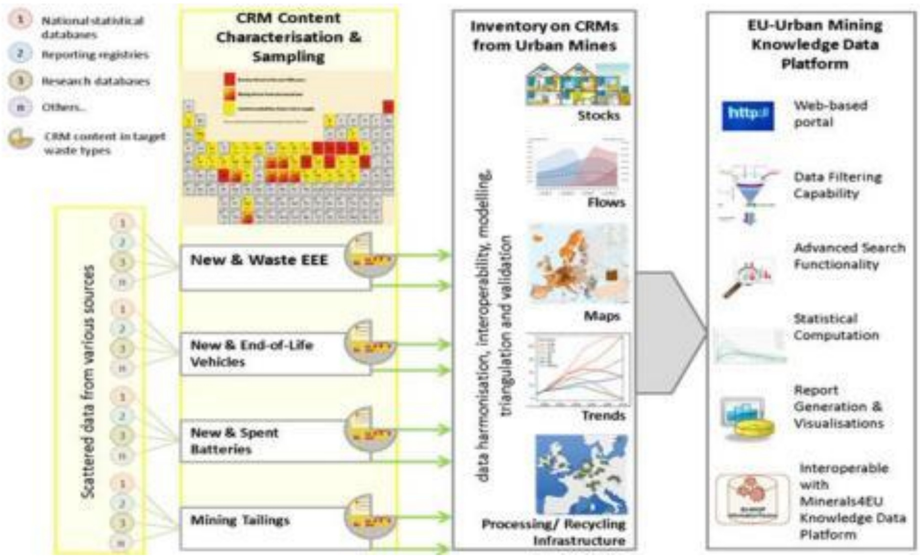
CRM Trends and Scenarios
Deliverable 2.4



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Prospecting Secondary raw materials in the Urban mine and Mining wastes

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PURPOSE

The purpose of this report is to extrapolate the time series developed in Deliverable 2.3, and combine this with the available data and literature from earlier work in the project, to generate insights for expected product and material composition developments. This will provide more information on the factors influencing future trends for CRM parameters on the composition of products and components.

Using the factors identified in Deliverable 2.3, short-term trends of CRM parameters in products and components, the impact on stocks and flows will be further determined by extrapolation in WP3. For the medium-term (up to 2020 and beyond) scenario development and analyses methods have been applied taking into account any potentially disruptive technology developments. These results will be used in Deliverable 5.2 to identify future scenarios and specifying the overall availability of secondary raw materials in the near-term future as displayed in Figure 1. The forecasted trends are also essential in completing Deliverable 3.4 on the Stocks and Flows model when product and material composition trends are connected to provide a comprehensive description and time series for secondary raw materials in the EU.

This report also considers market drivers for materials entering the urban mine in products and equipment. This will allow for more balanced projections of materials entering waste streams in the future and also facilitate consideration of the material choices made at an earlier stage in design and manufacturing.

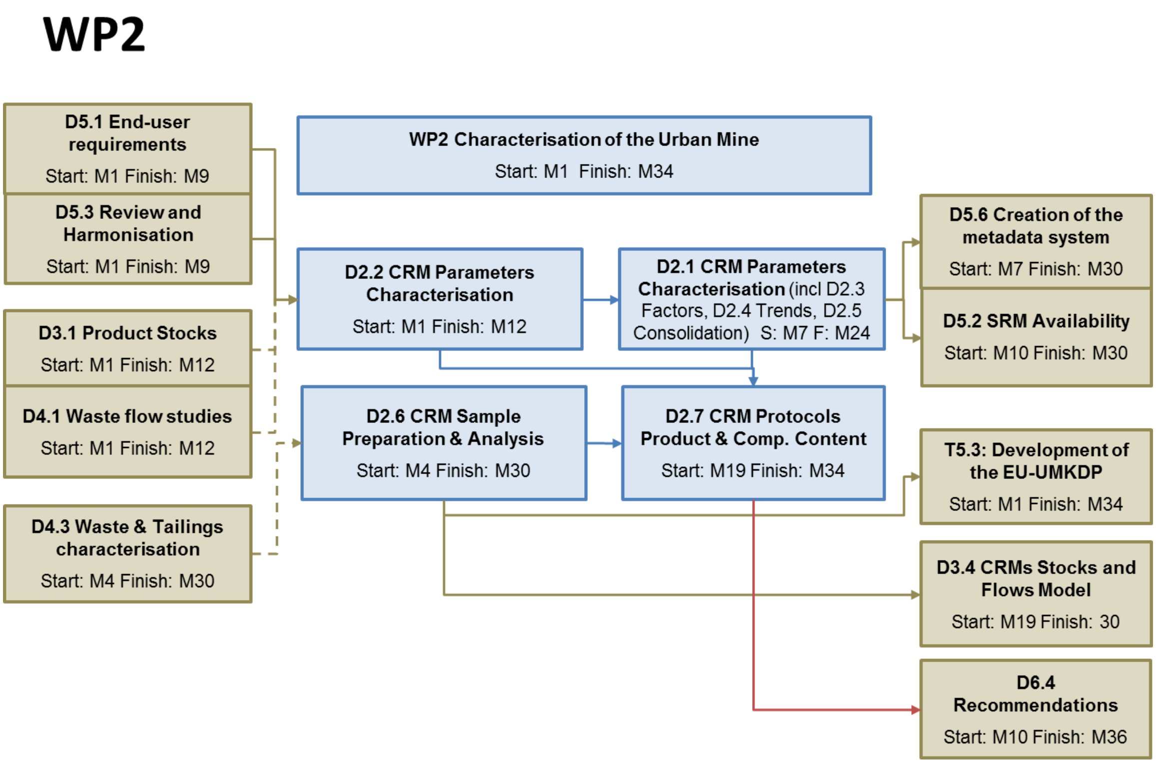


Figure 1: Pert Chart showing the relations between this and other deliverables

EXECUTIVE SUMMARY

In Europe and across the world, many attempts are made to predict the future technologies which will be placed onto the market in the future. This work by companies in developing and deploying technologies into markets is, however, not focussed on the flows of materials used and in particular not on critical materials (Peck, 2015).

Conversely the focus of ProSUM is to construct a comprehensive inventory identifying, quantifying and mapping CRM stocks and flows at national levels across Europe. ProSUM will communicate the results via an open-access Urban Mine Knowledge Data Platform (EU-UMKDP). This work is enhanced if near term future flows of materials into waste streams can be identified. In particular, to maintain and expand the EU-UMKDP in the future, further detail on CRM in waste flows is required. The medium term trend prediction for the selected CRM parameters has been based on selected, previously published, scenario development methods and techniques, which are integrated into a predictive framework for ProSUM.

This report generates insights for expected product and material composition developments. This could, with further development, provide reasonably reliable projections on future factors for the CRM parameters on the composition of products and components. Furthermore, consideration is given to the market drivers for materials entering the urban mine in products and equipment. In future, this consideration of market driven choices could allow for a more in depth study of materials entering waste streams helping inform material choices in design and manufacturing. This report does not seek to do this.

This Deliverable 2.4 builds on Deliverable 2.3, the factors identified for trends in CRM parameters of products and components. This report looks at the near-term future (up to 2020) through the analysis of data for current products which will appear in future waste flows. The approach used takes account of potential disruptive technology developments which also impact on products put on market and the resultant waste generated.

The approach taken was to first revisit the ProSUM bibliography (developed for the project) and scan for keywords such as “trend”, “forecast”, “future”, etc. and evaluate previous work and data which should be utilised. In a parallel step, to ensure a comprehensive capture of all available literature, a wider literature search was also conducted. Suitable encountered methods and techniques from previously published work were used to develop a framework for predicting and modelling near term future scenarios for CRM parameters.

A range of graphs in the form of curves, adoption curves, S-curves and Gartner’s Hype cycle are frequently used in the industry to describe the adoption and purchase of products. These graphs have been used, together with intelligence on critical material composition in products, to help develop CRM trends in products.

The findings for Electrical and Electronic Equipment (EEE), Vehicles and batteries (BATT) show a correlation between the curves for product trends and the application of materials which allows for the short term trends in CRM parameters to be observed.

It was observed that marketing curves can be useful, in relation to materials, when reviewing future CRM trends. The use of such curves provides a valuable method of not only estimating near future CRM trends but may also help to inform material choices as new technologies emerge.

Future trends of CRM in EEE flows

The use of materials for the design and production of electronics in EEE is evolving rapidly over time. There main trends are more products becoming 'smarter', smaller and more multifunctional. This is affecting the design and material composition of new products significantly. Due to the dynamic shifts in technology and material use in most EEE products, specific trends and forecasts are difficult to substantiate quantitatively.

Nevertheless, it was possible to apply the diffusion curves to the available information taken from literature to analyse for trends and establish the link between product and material trends for secondary raw materials present in stocks and flows. By means of analysing the specific trends in materials, components and products consumption, a summary of all trends in particular for new EEE products has been established for all UNU keys. By aggregating results per UNU key and extrapolating based on existing trends a result is generated for the expected quantitative trends in market sales until 2020. A more comprehensive qualitative overview of newly appearing, 'stable replacement products' and of, sometimes exponentially, disappearing products has been constructed in the form of the so-called UNU key catalogue in Annex 1.

Despite impressive growth in new functionalities related to the domains Mobility, Control, Power Generation, Sensing, Communication, Computation and Human Interface, the impact on the total quantities of secondary raw materials consumed and in stock is very limited. This is due to rapid miniaturization of these electronic components that is outpacing the growth in the number of pieces of EEE placed on the market. The example of gold in the 'Screens Collection Category' illustrates a rapid decline in total gold in WEEE amounts in future years, despite the substantial growth of flat panel displays in the last decade. This combined effect could affect the future value of waste products significantly and thus the current main economic driver for material recovery.

By multiplying specific component trends such as the average weight of printed circuit boards and their constituents over time with product unit sales projections, provides for future quantitative calculation. This will allow for unique and comprehensive CRM Stocks and Flows time series calculations in Deliverables 3.4 and 3.5 that will now include the trends analysed. It will also provide the basis for the 'coherent estimates' in Deliverable 5.4. The large number of multiplications and subsequent analysis of the results for all UNU keys and all CRMs individually, will produce more elaborated conclusions for total CRM content over time in these future deliverables.

Future trends of CRM in End of Life Vehicle flows

Based on observed current and historic trends for fleets and vehicle designs, qualitative conclusions for CRM in generated End of Life Vehicle (ELV) flows at present and in the future can be drawn. Observations regarding ELV flows which may be generated later into the future are also made, based on current discussions about the future development of the vehicle fleet and car designs. Quantified estimates for the total mass of CRM in vehicle stock and flows are not provided in this report. They will be generated as part of coming work in ProSUM.

Overall, it can be expected that the total mass of the vehicle stock and annually generated ELVs will increase slightly over the coming years. The diesel boom in the 2000s will lead to a higher proportion of diesel vehicles in the generated ELVs in future years. Electrified vehicles will only constitute a small minority of ELVs for a long time.

In terms of CRM quantities in the ELV flow, the shift of steel types may have had a relatively small impact, although some increase in niobium and molybdenum is likely. Only a small increase in cast aluminium content is expected in the coming years, as its use in new vehicles has only grown slowly in the past decade.

With the rapid increase of wrought aluminium use, magnesium as an alloying element is also increasing. The late introduction of catalytic converters for diesel cars combined with the European diesel boom in the 2000s will lead to a large increase in platinum available from ELVs in coming years. It is clear that electrical and electronic devices have increased significantly in new vehicles over the last years, which will lead to an increasing occurrence of these devices in ELVs in the future.

Future trends of CRM in BATT flows

The CRM containing components of batteries are rare earth elements in NiMH batteries, cobalt in the cathode materials in Lithium Cobalt Oxide (LCO) and Nickel Manganese Cobalt/Nickel Cobalt Aluminium (NMC/NCA), and natural graphite in the anode. NiMH batteries are being replaced by lithium-ion batteries, which is a very heterogeneous group of electrochemical systems using a high variety of material combinations.

The battery market depends on the development of the markets for battery-containing products. Decisions taken by the battery producers in practice relate to the selection of the type of electrochemical that will be used in the product and its material composition. These decisions heavily impact on the consumption of CRM. Two interlinked strategies are possible to limit or reduce the CRM demand for batteries:

- Select battery systems that do not contain the CRM-containing components e.g. with sodium nickel chloride batteries or lithium-ion batteries with Lithium Ferrous Phosphate (LFP) or Lithium Manganese Oxide (LMO) cathodes; or
- Reduce the CRM concentrations in the CRM-containing components.

Overall trends

Overall the approach of looking at what is coming onto the market is a good indicator of materials in the urban mine going forward. Whilst this in itself is no surprise, this report highlights that the focus of many who seek to develop an understanding of the urban mine, tend to observe waste flows rather than market and technology trends for product coming on to market. At the same time, those in companies who make choices on which products will be successful in the market place, tend not to consider the impact on materials in the urban mine. This report has attempted to bring the two fields together to help in developing urban mine trends and scenarios going forward by providing a more comprehensive qualitative and quantitative analysis of CRM trends in products and components.

1 Introduction

In Europe and across the world, many organisations, in particular companies, attempt to predict which technologies will satisfy consumer demand and what the resultant technology and market trends will be. Even more valuable to companies is to be able to accurately predict which technologies will be commercially successful and widely diffuse into a market. Manufacturing companies spend a significant amount of time and effort trying to ensure they make the right technology and product choices in their business planning.

Such market research, in developing and deploying technologies into markets is, however, not focussed on the flows of materials used and, in particular, not on critical materials (Peck, 2015). Consideration of materials in technology development is made at the design stage in relation to many factors, including price and ensuring a match to existing part and component supply chains. Factors such as if materials or substances are banned or otherwise controlled for environmental reasons e.g. by the REACH Regulations, are managed as part of sourcing, compliance and supply chain management.

It is in this landscape that the focus of ProSUM is to construct a comprehensive inventory identifying, quantifying and mapping CRM stocks and flows at national levels across Europe. ProSUM will communicate the results via an open-access Urban Mine Knowledge Data Platform (EU-UMKDP). This work is enhanced if near term future flows of materials into the waste streams can be identified. A key way to develop this forward trend analysis is to consider what is entering the market and the various maturity levels of products and components over time. In particular to maintain and expand the EUUMKDP going forward, future quantification of CRMs in waste flows is required. The medium term trend prediction for the selected CRM parameters is generated based on selected scenario development methods and techniques, which have been integrated into a predictive framework for ProSUM.

This report, Deliverable 2.4, builds on Deliverable 2.3 which identified the factors in the trends of CRM parameters in products and components. This report looks at the near-term future (up to 2020) through analysis of data of current products which will enter future waste flows, taking into account potential disruptive technology developments, in particular products in the 'hype' phase (rapid growth in take up), as well as careful extrapolation where possible based on existing information.

1.1 Approach

The general approach was to firstly describe in a qualitative manner the market trends in the three products groups. For EEE in Section 2.1, this includes and focuses on trends in intelligent hardware, rapid miniaturization of electronic components, convergence of product functionalities, cross-over products, and digitalisation. For vehicles in Section 3.1, the focus is on trends in fleets of vehicles related to average mass, evolutions in drive train technology and the consequences of electrification of both the drive train and the increasing use of electrical and electronic components like motors, displays, etc. For batteries in Section 4.1, the focus is more on the dynamics in battery chemistries in relation to smaller, lighter and higher density battery cells. Also, the effects of more electric mobility and energy storage are taken into account. All these trends in the three product groups will significantly affect the consumption and availability of secondary raw materials.

Secondly a revisit of the ProSUM bibliography (developed for the project) has been undertaken, to evaluate and include past research on “trends”, “forecasts”, and “future”. This is supplemented by a description of the existing quantitative information from previous deliverables for EEE, battery and vehicle market inputs and stocks which is evaluated in Section 2.2, Section 3.2, Section 3.3 and Section 4.2 for EEE, vehicles and batteries, respectively.

Thirdly, for newer products and components related to the latest technologies, the methods and techniques observed in various publications are used to develop a framework for predicting and modelling near term future scenarios for CRM parameters. These scenarios are based on observed trends and feedback from producers, recyclers and research organisations. The underlying approach in this task is the use of product marketing approaches to help spot material trends in the near future. This is undertaken to help understand the cycles of product in markets and when/what will enter the waste stream at a later point in time. In particular, there is a focus on various graphical displays of trends in sales, market penetration or market saturation, adoption by different consumer groups and technical performance as a function of time in the form of adoption curves, s-curves and hype cycles which build upon/interconnect with products coming onto market. These graphical displays and connected theories are explained in the following Section 2.3 for EEE, Section 3.5 for vehicles and Section 4.3 for batteries. Finally, for selected products, a full multiplication of product trends times component and materials trends is displayed at the end of these product sections.

1.1.1 Diffusion Theory and Adoption Curve

Diffusion theory is a collection of concepts which are used to understand the take up and use of products by either business to business ‘B2B’ or business to consumer ‘B2C’ consumers. Rogers first introduced this field and his work began when looking at products in developing countries (Rogers, 1962). The important aspect is the adoption and use of products over time (Rogers, 1983). Figure 2 shows the pattern of diffusion and is used by companies keen to target the sale of product to the 5 types of users from innovators to laggards. Innovators are people who like to have the newest type of product at the earliest point in time. Laggards are those people who are happy to wait until a product has been around for a long time and is almost ‘out of date’ before buying it.

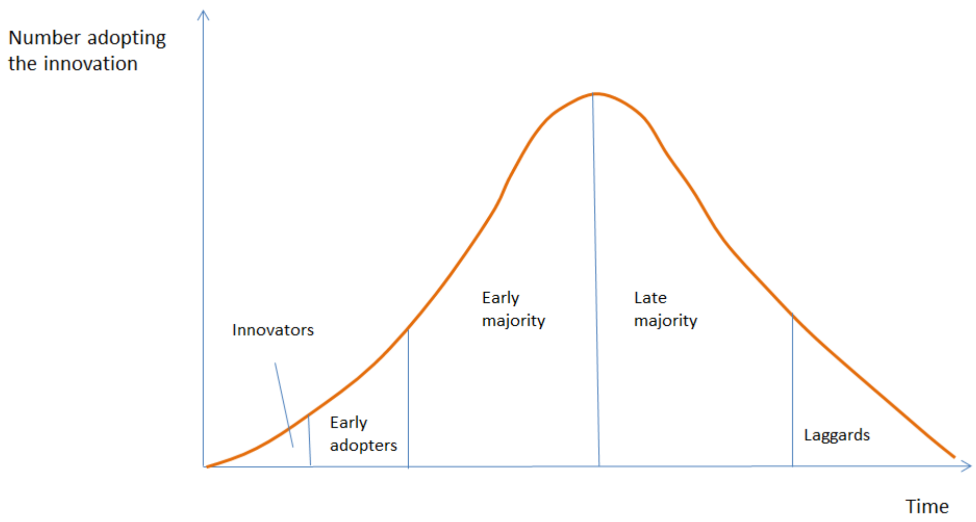


Figure 2: Rogers's diffusion curve of adaptors over time (adoption curve). Derived from OU 2006, derived from Rogers 1983.

1.1.2 S-curve theory

Building on diffusion theory, a more sophisticated model is analysis using s-curve theory. This shows where products undergo continual incremental innovation during their lifetime. The speed of this innovation is shown by the slope of the curve. At the top of the S, the product is developed as far as possible and room for marketable improvement is exhausted. This is shown in Figure 3 below. What is important to note is the use in this Figure of the aspect of technical performance. This aspect often relates to advances in materials.

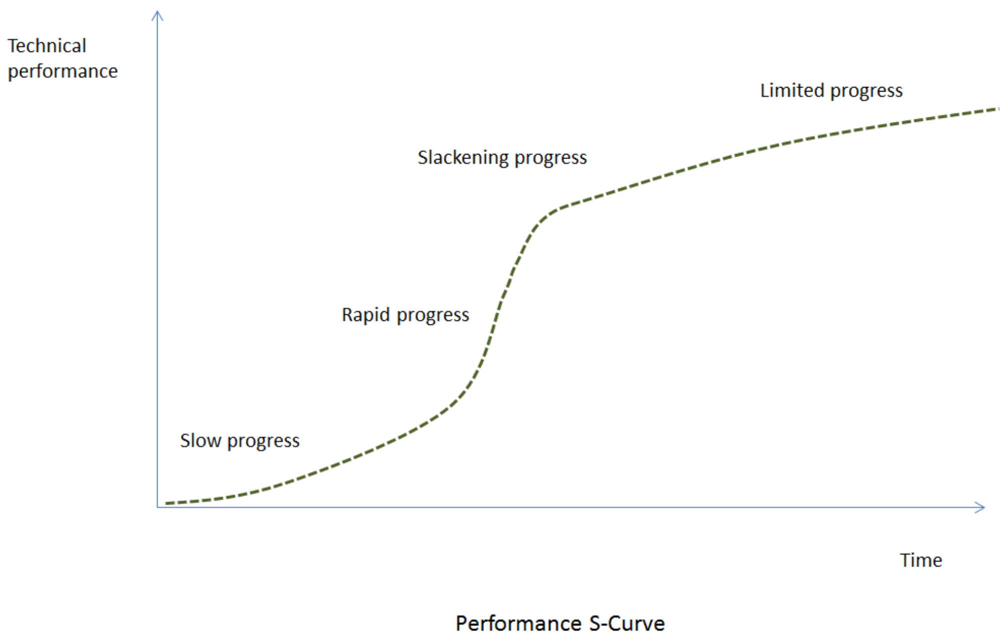


Figure 3: The technical performance S curve showing an evolutionary development, adapted from OU 2006

A connection between the Rogers diffusion curve and a different S curve can be seen in Figure 4. In this Figure, the percentages for cumulative adopters (taken from Rogers above) is shown on the Y axis. This now gives an indication of the distribution of users of a product over the period of time that that type (or version) of product is in the market.

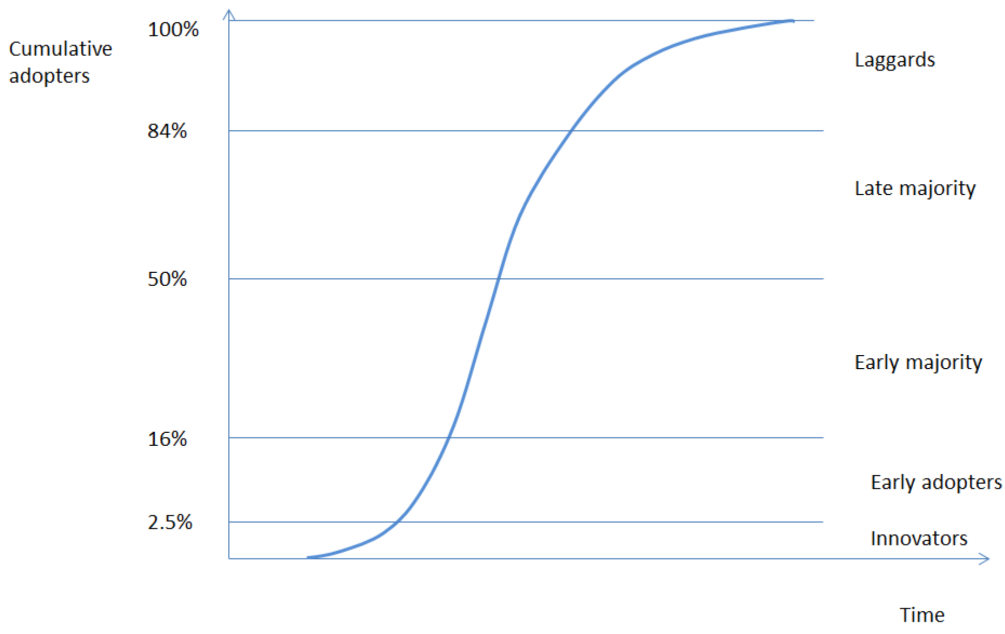


Figure 4: An S-curve of cumulative adopters. Adapted from Trott, 2008

Where a product is popular in the market but the technology/features are dated, they can be enhanced or upgraded. These are strategies used to extend the technical performance of a product and this can be seen in Figure 5. Again materials advancements to enhance the technical performance of the product play an important role.

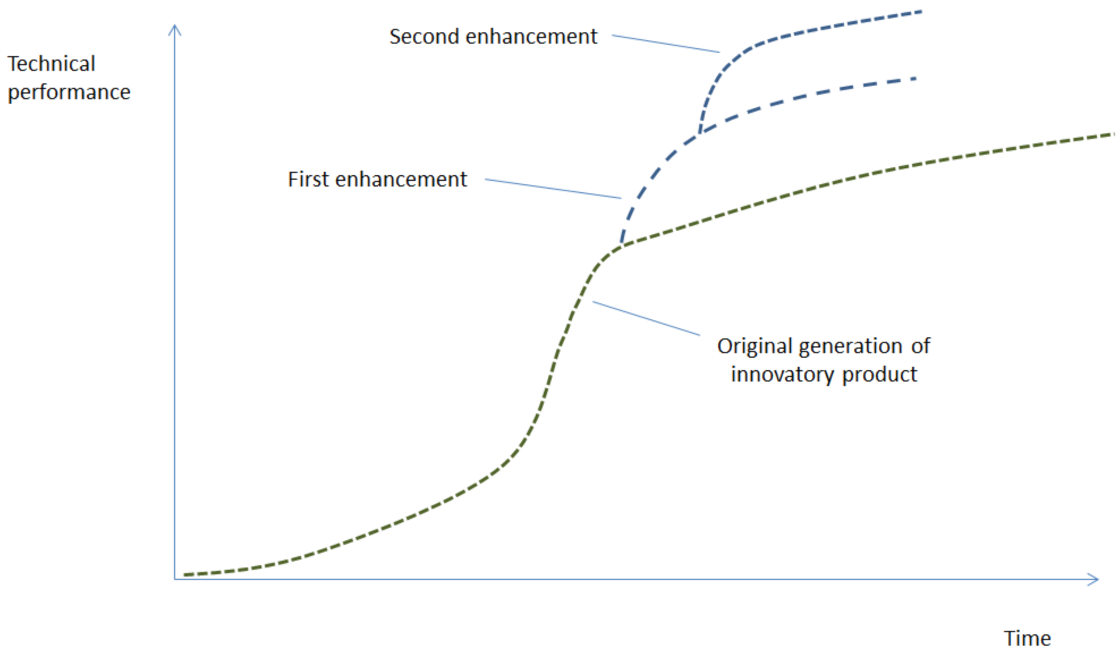


Figure 5: S-Curve analysis – product enhancement. Derived from OU 2006

1.1.3 Gartner's Hype Cycle

In their 2003 publication, Linden and Fenn explain that the Gartner Hype Cycle provides a view of the relative maturity of technologies. They attempt to separate the hype of an innovative technology from reality and such curves are used to help companies decide when they should adopt a new technological innovation into their product offering (Linden and Fenn, 2003).

The decision of a company on whether to adopt an innovative new technology depends on a good understanding of the maturity of that new technology. The adoption curves and s-curves shown above help in this but they do not chart the very early stages of the life cycle of an innovative technology and, importantly, how it may evolve.

The very early stages of the evolution of a technology are often characterized by user (for example via social media) and media over-enthusiasm, followed by a period of disillusionment as the true performance of the technology becomes clearer. This is followed by a gradual understanding of the technology and where it fits. The key message is companies should not invest in new technologies simply because they are being over-hyped nor should they ignore them because they don't match up to early over-expectations (Linden and Fenn, 2003).

Linden and Fenn identify the following five overlapping stages in a technology's life cycle:

- Technology Trigger: In this stage, a technology is conceptualized. There may be prototypes but there are often no functional products or market studies. The potential spurs media interest and sometimes proof-of-concept demonstrations.
- Peak of Inflated Expectations: The technology is implemented, especially by early adopters. There is a lot of publicity about both successful and unsuccessful implementations.
- Trough of Disillusionment: Flaws and failures lead to some disappointment in the technology. Some producers are unsuccessful or drop their products. Continued investments in other producers are contingent upon addressing problems successfully.
- Slope of Enlightenment: The technology's potential for further applications becomes more broadly understood and an increasing number of companies implement or test it in their environments. Some producers create further generations of products.
- Plateau of Productivity: The technology becomes widely implemented; its place in the market and its applications are well-understood. Standards arise for evaluating technology providers.

Comparing the Hype Cycle charts across the years, not only gives a sense of the new products and technologies on the horizon, but also those that have gone from early prototypes to become more widely adopted. A good example is 3D printing that has moved from the peak of expectations to becoming a more matured technology approaching the plateau of productivity. These five stages are shown in Figure 6 and are positioned along the hype cycle.

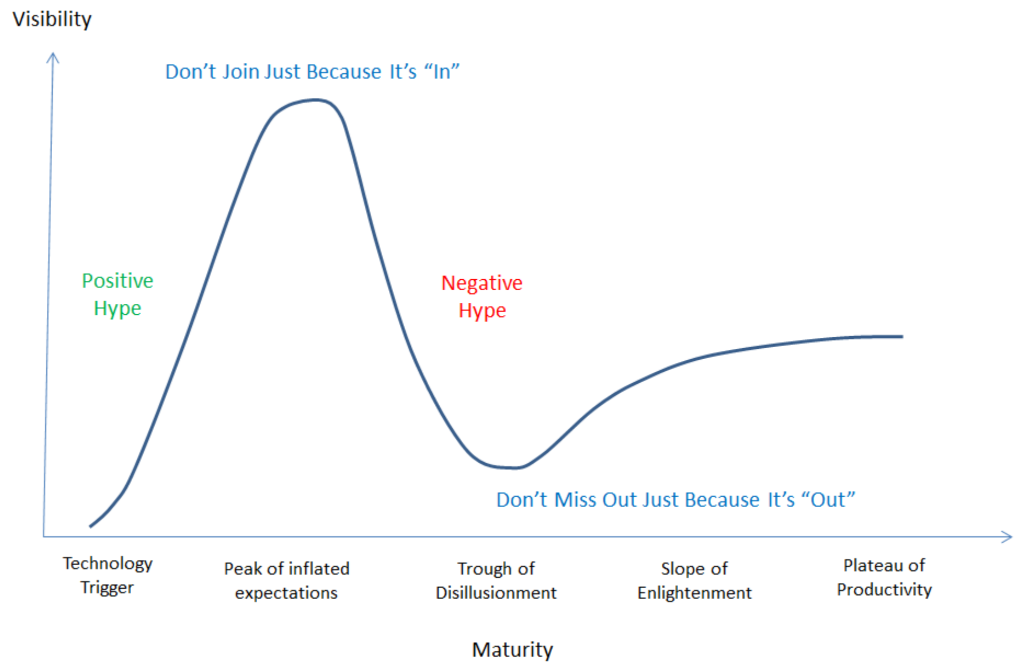


Figure 6: The Hype Cycle. Linden and Fenn, 2003

1.2 Methodology

1.2.1 The connection between market curves and the materials value chain

The 3 curves shown above can be brought together as seen in Figure 7 below. This shows a hype cycle together with the adoption curve and S-curve. The vertical line shows any given point in time. The key point to note is the 3 curves are aligned in time sequence.

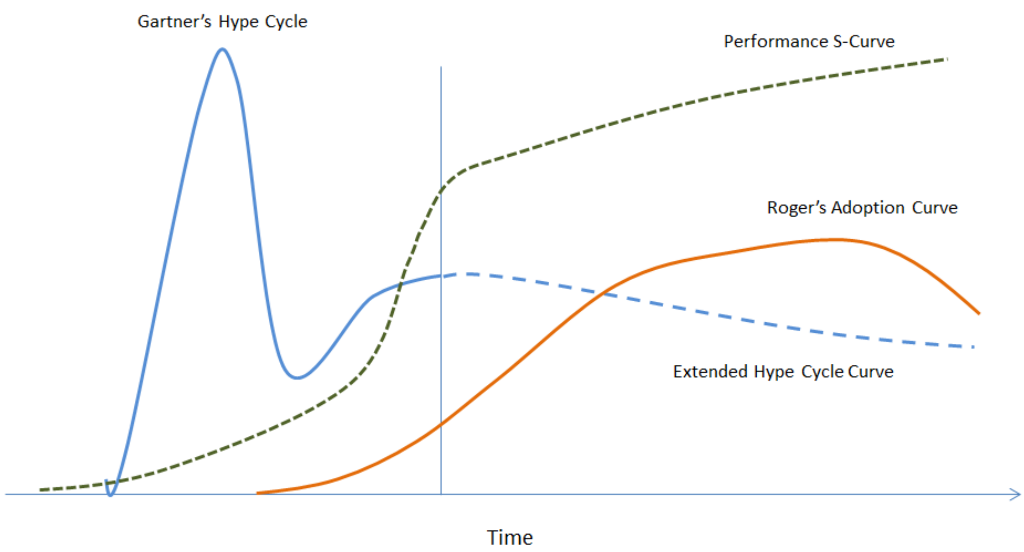


Figure 7: All three curves shown together. Linden and Fenn, 2003

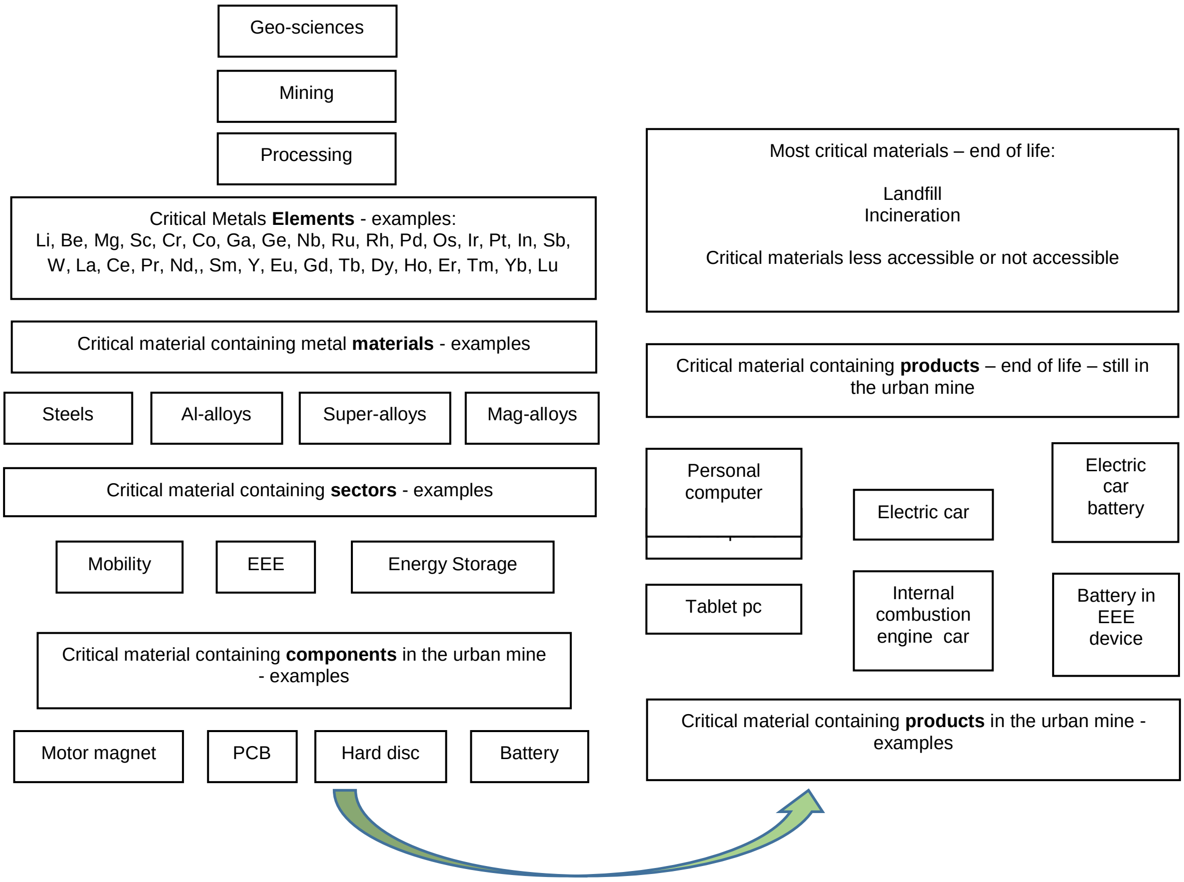


Figure 8: The critical materials value chain – wide range of fields (Peck, 2016)

For application of these theories it needs to be considered that all materials are part of a materials value supply chain as depicted above. The technologies and innovations of the 21st century have driven the pull of more materials out of the materials science lab, via materials producers, and into products. An exemplar critical materials value chain can be seen in Figure 8 above, where examples of materials, sectors, components and products are shown.

The materials value chain shows how the input of elements can produce the materials key to the technological properties that delivers the desired performance shown in the adoption curve in Figure 9 below.

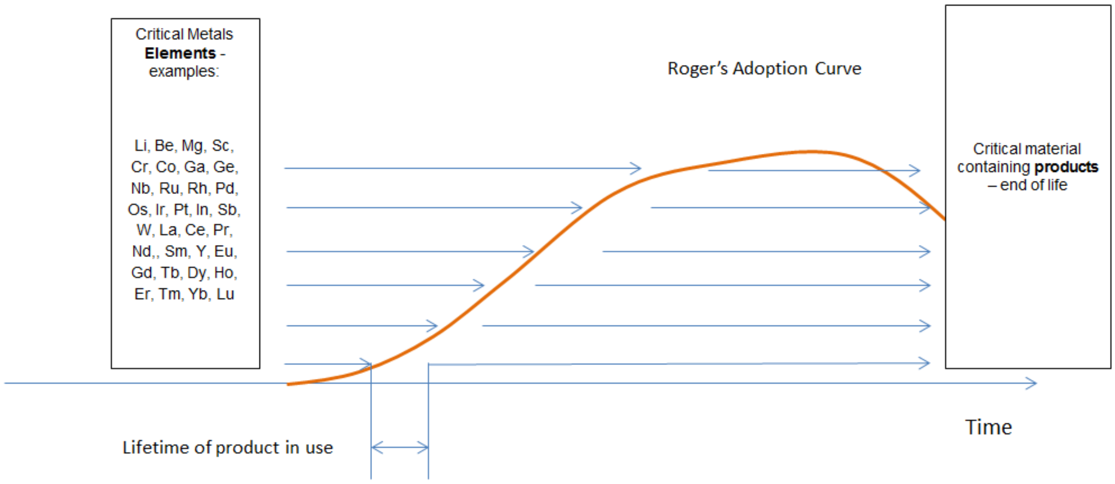


Figure 9: Critical materials to technical performance for S-Curve leading to, over time, product end of life and entering waste stream.
(Materials are not normally considered in the use of such curves).

The use of the 3 types of curves is used in marketing and innovation management fields and a key aspect is the introduction of new technical features to ensure the development of the technical performance. An important ingredient in this technical activity is the use of materials. In particular, the marketing and innovation activity creates a pull of advanced materials out of the materials laboratory to enable the product to technically perform according to market demands.

In another example of materials considerations, the Gartner's Hype Curve is also adapted (Figure 10) to show how constituent materials can change as new generations of products are introduced and developed as the technology seeks a place in the market.

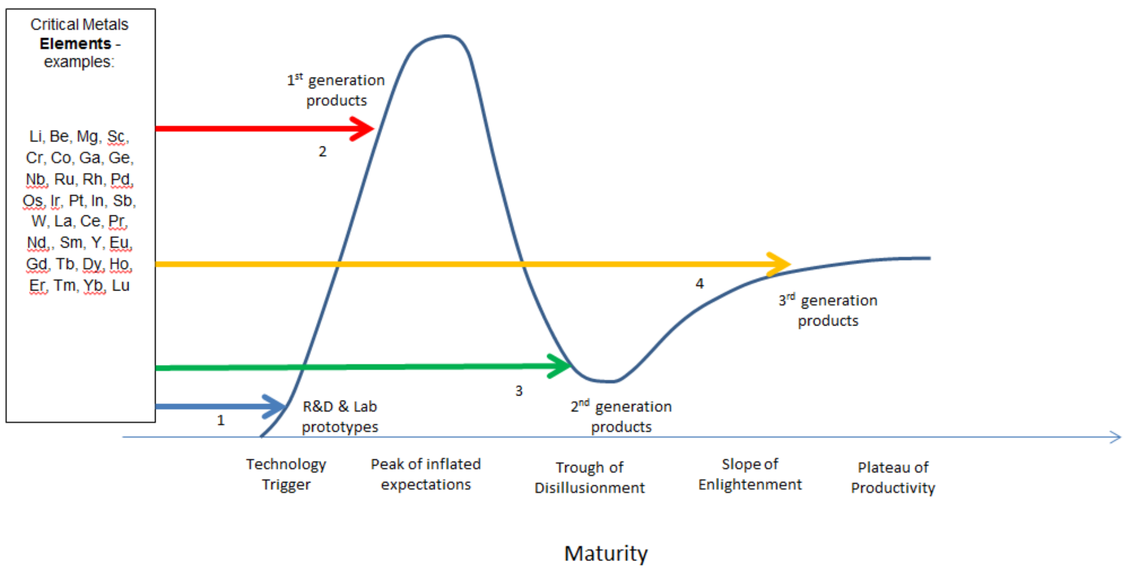


Figure 10: Gartner's Hype Cycle showing changes in material composition as the prototype and generations of the technology evolves.
(Materials are not normally considered in the use of such curves.)

The Figures above show both how new products and technologies evolve and also indicate how materials composition usually plays an important role in that evolution. This principle is what has been sought in the literature, to help map short term future materials trends and scenarios in the selected applications.

1.2.2 Methodology to forecast CRM parameters

The method used to forecast future CRM parameter scenarios is a stepped approach where firstly the S-curves for each product category (batteries, magnets in vehicles and EEE) are taken or derived from the End Note Data Base (EN DB) literature. This facilitated the identification of trends that will affect CRM parameters in each product category. These trends will be projected to the near future, up to 2020.

Key to this work has been accessing and using the data. The literature has been reviewed for data on the weight, composition, stocks, flows, lifespan, etc. Any gaps have been highlighted, but at this stage not addressed. Based on scenarios of likely adoption rates and product lifespan estimates, both at a sub-component as well as for example products, an estimation of the types of material demand in the near future for the upcoming technologies and products has been made.

The outputs from the work shown above will be applied in WP 3, where future stock and flow modelling will need to be based on near term future scenarios for individual CRM parameters.

Disruptive technology developments are by definition difficult to predict. However, this framework has been developed and tested to observe near-future flows for CRM and CRM parameters in the stocks and waste stream in particular.

2 Electrical and Electronic Equipment

2.1 Introduction - Product Trends EEE

Incremental and disruptive innovations in EEE products result in new products being introduced to the market, some that even carve out a new product category. Recent examples of once new products that are more common place now, and that went on to create a new product category are tablets and smart watches. These type of developments impact on the composition of EEE products significantly and for some specific products their chemical elements rather disruptively.

As an example, in 2017, the Consumer Electronics Show (CES), the world's largest trade fair for consumer electronics celebrated its 50th year. The first Video Cassette Recorder (VCR) was launched at the CES in 1970, the CD player in 1991, and the first ever Nintendo game console in 1985. The range of products showcased and launched at the CES has grown exponentially since then. At the most recent edition of the show held in Las Vegas in January 2017, the products with the greatest hype (trending on social media, widely discussed, media reports, etc.) around them were drones, wearables, robots of all shapes, sizes and functions harnessing the power of Artificial Intelligence, and Machine Learning technologies.

Table 1: Most hyped products at the CES 2017

Category	No. of exhibitors at CES 2016	% Increase over 2015
3D printers	58	31%
Virtual reality	46	68%
Robotics	23	71%
Wearables	33	175%
Drones	29	315%

Source: CES (http://www.cesweb.org)

The Hype Cycle, as discussed in Section 1.1.3, is a graphical representation of the life cycle stages a technology goes through from conception to maturity and widespread adoption. The hype cycle identifies five overlapping stages in a technology's life cycle:

- Technology Trigger;
- Peak of Inflated Expectations;
- Trough of Disillusionment;
- Slope of Enlightenment; and
- Plateau of Productivity.

Comparing the Hype Cycle charts across the years, not only gives a sense of the new products and technologies on the horizon, but also those that have gone from early prototypes to become more widely adopted. A good example is 3D printing that has moved from the peak of expectations to becoming a more matured technology approaching the plateau of productivity.

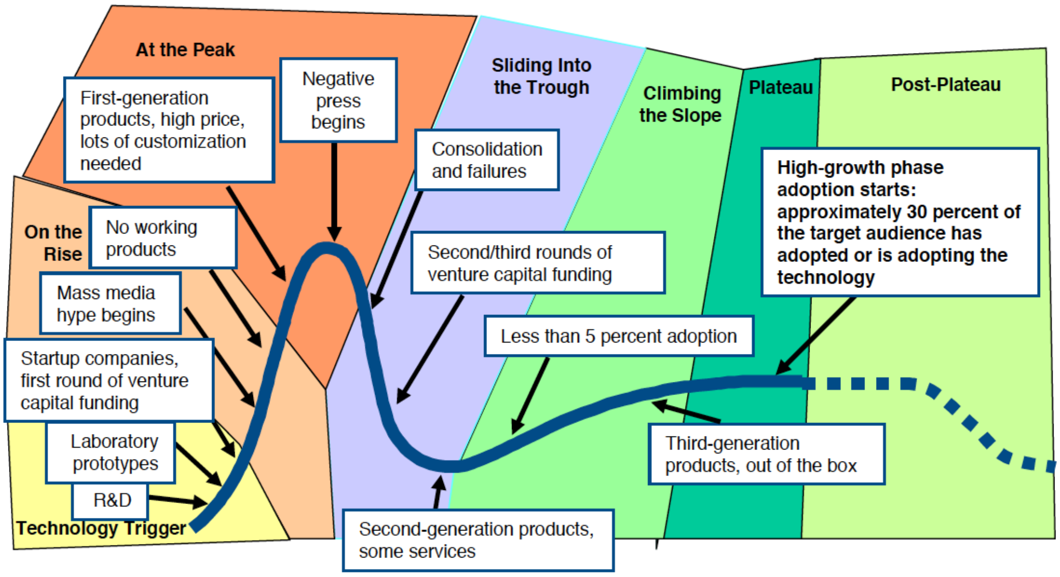


Figure 11: The Hype Cycle charts. Gartner 2003.

As explained in Section 1, the S-curve of product diffusion starts at the point the product move out of the 'Trough of Disillusionment", with the innovators beginning to adopt the product, followed by the early adopters before reaching the "Plateau of Productivity" once the late majority and laggards adopt the product, when the adoption of the new product or technology is complete. More information on the EEE related hype cycles can be found in Annex 2 The Hype Cycles and S-curves for EEE.

An assessment of new products introduced in the past couple of years, and those showcased at the CES in 2017, indicates several trends for EEE products that in turn will impact the material composition, including CRM in the products:

1. A trend towards 'smarter' hardware where products are increasingly fitted with sensors, communication and data modules and other technologies, making the products more intelligent.
2. A trend towards miniaturization of hardware where the same and more functions are performed by smaller and smaller devices.
3. A trend towards convergence whereby multiple products, often from different product categories, are integrated and combined e.g. phones and cameras, Amazon echo etc. whereby products have similar underlying technologies connecting them.
4. Cross-over products where more products are overlapping the business and consumer domains, moving from desktops, laptops and laser printers to 3D printers, drones, medical devices etc. which were initially introduced as business to business products.
5. 'Digitalization' of products previously without any electrical or electronic components bringing a larger gamut of products with embedded electronics and thereby greater diffusion of CRM.

2.1.1 Trend towards Intelligence in Hardware

EEE products, as well as previously non-EEE products are increasingly loaded with electronic sensors and features ranging from voice control, data storage, and Wi-Fi connectivity etc. There is a trend for hardware devices evolving from being manual to automated to 'smart' and finally autonomous. Manual devices are those that require human intervention to perform any task. For example, TVs, vacuum cleaners, and irons all needed human intervention to switch them on or off and perform the function expected. Sensors, if any, are primarily provided for safety during operation and the products typically have no computing capabilities.

Over the last decades, the trend has been towards devices equipped with additional sensors and logic controllers that allowed devices to perform a series of operations unsupervised, improving the human-machine interface. Such 'automated' devices can be programmed to sense and respond to certain specified operating conditions. However, these still require human intervention to automate the task, for example, DVRs that can record shows at pre-set times on their own, or washing machines that can be programmed to start at a certain time and adapt the water consumption to the load etc.

Increasingly, these devices are in a next stage of evolution, made 'smart' by equipping them with more powerful computing capabilities, information storage, bidirectional connectivity with the user, and a richer human-machine interface (touch, multimedia etc.). With the advent of the 'internet of things' (IoT), such smart home products will become more ubiquitous, with everyday devices getting an IoT upgrade. Wi-Fi connectivity and app-based control are already available in small kitchen-counter appliances, refrigerators, thermostats etc. Increasingly, the 'smart' will have IoT enabled doorbells, lightbulbs, ceiling fans, smoke alarms, washing machines, and much more. Such devices enable more customization and personalization of the user experience as well as greater functionality and complex use patterns through their use of additional sensors and computing ability. A single device may also be able to perform multiple functions which previously required separate devices. Devices may communicate with other devices and may store information in the cloud from where it can be shared with other people e.g. smartphone, smart refrigerator, smart HVAC, smart lighting etc. As seen in the Figure 12 below, smart home device shipments are expected to grow at an exponential rate in the next 3-4 years.

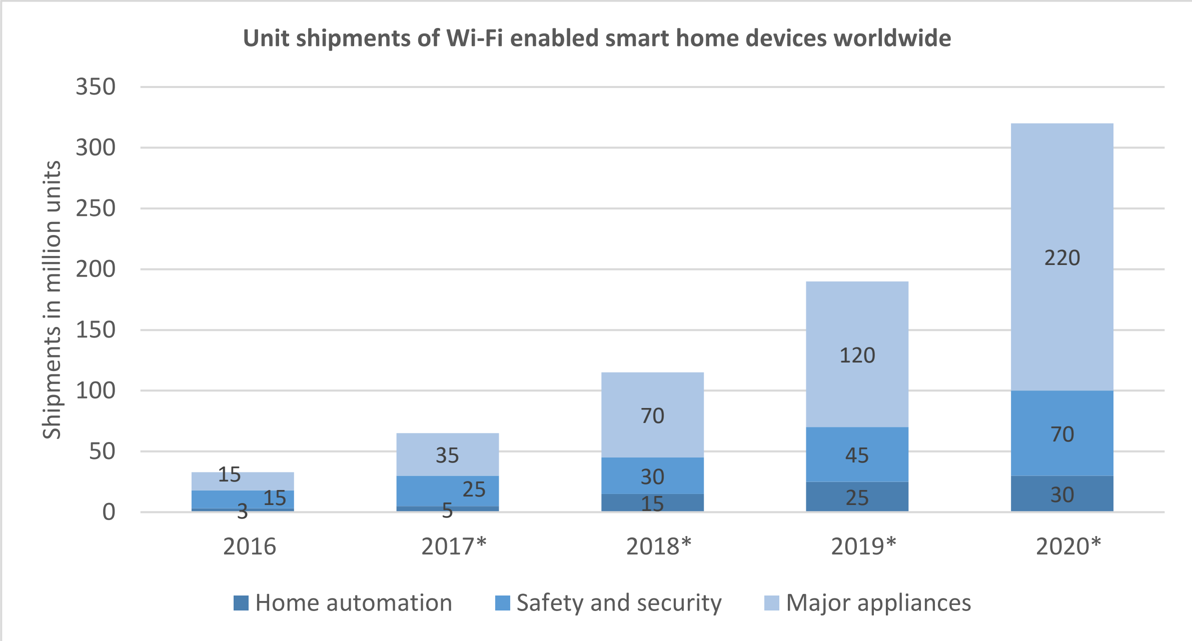


Figure 12: Shipments of Wi-Fi enabled smart home devices worldwide. Source: IHS & Statista estimates

Autonomous devices usher in the age of Artificial Intelligence (AI). Large technology giants as well as start-ups in the last two or three years are piloting and also introducing into the market devices that operate using sophisticated AI programs, built on analysis of large complex datasets gathered and available through multiple sophisticated sensors. They contain powerful computing capabilities, information storage, network connectivity and often have a sophisticated human-machine interface such as voice or gesture control. These devices can perform their tasks with little or no human intervention. Examples of autonomous AI-based devices are self-driving cars and trucks being trialled in many countries, and delivery drones with navigational capabilities etc. Refrigerators, vacuum cleaners and personal assistant robots are some consumer products that are already witnessing the integration of AI technologies.

At the material level, this trend of increasing hardware intelligence, from manual to autonomous devices is driving demand for higher computing power, more sensors, storage and connectivity. Broadly all product categories have reached a mature level of automation. Listed in Table 2 below are some examples of products which represent the next stage of evolution from manual towards smart onto autonomous. Also Annex 1, the UNU key catalogue for the most common past, current and future devices, gives a more comprehensive picture.

Table 2: Trend towards increasing hardware intelligence

WEEE categories	Manual device	Smart devices	Autonomous devices
1. Temperature exchange equipment	Traditional refrigerator 	Smart fridge – camera, touch screen, wifi connectivity, voice control 	
2. Screens, monitors, and equipment containing screens having a surface greater than 100 cm2	Traditional Projector 	Smart TV Smartboards 	
3. Lamps	Basic LED light 	Smart LED lights 	
4. Large equipment	E-bikes 	Hoverboards  Drones 	Smart vehicles, Personal/ Voice-activated robots/ AI assistants/ Robot butlers 
5. Small equipment	Traditional vacuum cleaner  Traditional weighing scale 	Smart weighing scale  Home diagnostics  Smart thermostat	Robot vacuum cleaner  Smart home assistants 

			
6. Small IT and telecommunication equipment (no external dimension more than 50 cm)	Feature phone 	VR headset  Smart Watch 	

2.1.2 Trend Towards Miniaturization

Personal computers provide a useful illustration of the product trend towards miniaturization, having evolved from heavy boxy desktops to sleek laptops and All-in-One desktops that integrate much greater computing power and functionality in ever smaller and flatter forms. The push for smaller parts comes from both the need for smaller assemblies for greater portability, and the need to reduce material costs. This does mean from a strict material consumption in products point of view that doing more with less as an eco-design practice is very apparent. There is little information available to determine if this also holds or the manufacturing stages.

The trend towards miniaturization of products is linked to developments and innovation at the component level. Computing modules are becoming smaller which allows them to be embedded into objects such as wearable devices, clothes, tattoos, shoes etc. Computer chips now have features measured in billionths of a metre. Sensors that once weighed kilogrammes fit inside a smartphone. Current research and innovation is pushing this even further with the development of sensors the size of a grain of salt. Micro-Electro-Mechanical Systems, or MEMS, is a technology that, in its most general form, can be defined as miniaturized mechanical and electro-mechanical devices and structures that can vary from, well below one micron on the lower end of the dimensional spectrum, all the way to several millimetres.

Likewise, the types of MEMS devices can vary from relatively simple structures having no moving elements, to extremely complex electromechanical systems with multiple moving elements under the control of integrated microelectronics. MEMS sensors are used in a wide range of applications from biotechnology and medicine to communication, automotive and consumer electronics. For example, MEMS accelerometers have displaced conventional accelerometers for crash air-bag deployment systems in vehicles. The previous technology approach used several bulky accelerometers made of discrete components mounted in the front of the car with separate electronics near the air-bag and cost more than $50 per device. MEMS technology has made it possible to integrate the accelerometer and electronics onto a single silicon chip at a cost of only a few dollars. These MEMS accelerometers are much smaller, more functional, lighter, more reliable, and are produced for a fraction of the cost of the conventional macroscale accelerometer elements.

MEMS based sensors that can measure temperature, heart rate, blood pressure, detect speed, light, minute vibrations etc. are already available at a miniaturized scale to be able to be woven into clothing, giving rise to a whole new category of EEE in the form of smart garments. Figure 13 below provides an indication of this trend towards miniaturization with the adoption of smart wearable devices such as smart watches and fitness monitors that will increasingly be embedded into garments. At the very technological frontier is the concept of 'smart dust' based on MEMS with sensors that can detect and communicate across a mesh network of IoT devices.

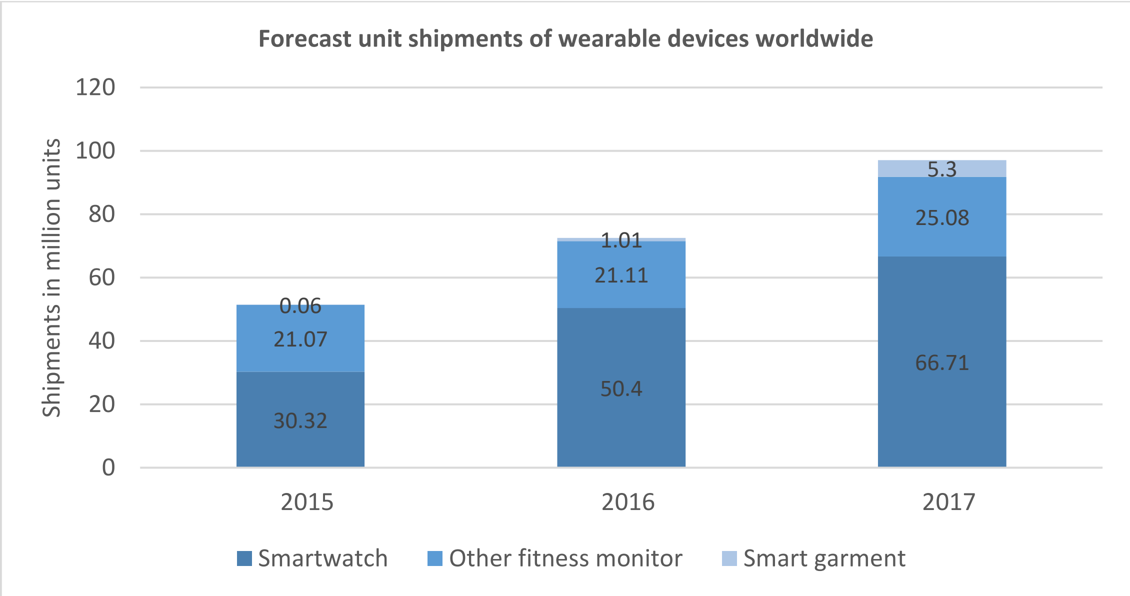


Figure 13: Sensors on your fingertips – miniaturized components embedded into clothing. Source: Gartner and Statista

The miniaturization of products and components has implications at the material level. For example, planar transformers, that have spiral patterns etched on a PCB, offer significant improvements over traditional copper wire wound transformers. A planar transformer can handle more power than a wound transformer of the same size and weight, so planar transformers reduce the space the transformer requires in the end product. Thus, to do the same job as existing transformers, the new design uses less steel and copper wire, resulting in direct material cost savings and indirect cost savings that result from the smaller enclosure needed to hold the transformer. This trend towards miniaturization is also driving demand for portable energy sources, particularly those with high energy to weight ratio as well as low power computing and connectivity modules.

2.1.3 Convergence

Products increasingly have multiple functionalities, and these often overlap. Smartphones are an illustration in convergence whereby a device previously used for a single function of telephone calls evolved to include multiple functions provided by cameras, PCs and TVs, with the integration of image capture, Wi-Fi and video functionalities. In the automotive area, there are several new entrants innovating in the areas of electrification, automation, and connectivity. Platforms for entertainment, communications, assisted driving, predictive maintenance, and vehicle intelligence are proliferating and converging.

Another area of convergence is in home automation and personal assistants with devices such as Amazon Echo bringing convergence at home. Such convergence will make it possible to have seamless integration and usability across devices; access to various types of information (entertainment, communication); and control of various devices such as heating, lighting, security etc. Much of the requisite technology that will enable this convergence already exists. There are sensors, actuators, communication protocols, application platforms, user hubs, and interfaces for almost everything. This will mean many products, that are currently completely disconnected from each other, also at the component level, will share many similar components that will be required for this convergence. Products as diverse as smart refrigerators and home diagnostics devices will share many sub-systems at the component level for communication, computation and storage, meaning that similar materials and elements will be dissipated across more products.

2.1.4 Cross over products

The origin of many commonly used technologies and products has been in military and industrial applications that have over time been adopted by households and individual consumers. Computers and in-car navigation systems are just two common examples of products created for military use becoming widely adopted by civilians. Drones, building security and automation systems, electric vehicles, medical diagnostics equipment, and 3D printers are some of the new products that are crossing over from a purely commercial/industrial/military use to more common consumer product. By the measure of the number of companies present at the CES 2017, some of the most prominent technologies that saw a large jump in the number of product manufacturers was for products that were in the cross-over category. In particular, drones, Figure 14, which saw the number of exhibitors more than triple from last to this year (see Table 1 above).

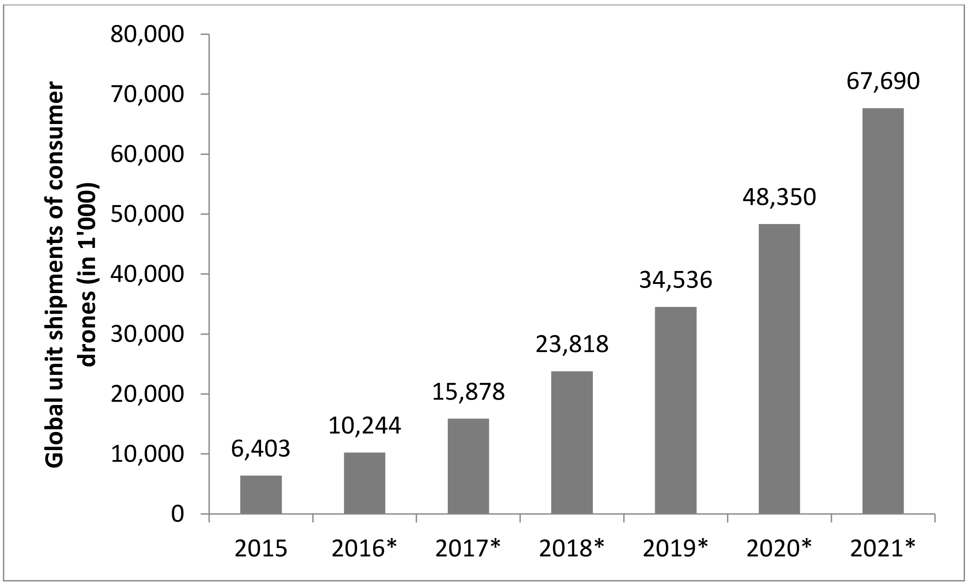


Figure 14: Consumer drone shipments estimated to grow exponentially. Source: Tractica, 2015

2.1.5 Digitalization

Products such as clothing, shoes, socks, gloves, products considered outside the domain of electronics, are increasingly incorporating circuits, displays, sensors, communication modules etc. that technically bring them within the scope of electronic products. So-called 'smart garments', 'wearable tech', or 'e-textile' products are only available on the fringe and for very niche applications. However, from the first tentative steps in 2015, wearable tech has gained momentum as more and more companies, including established brands of clothing and shoes, have entered the market. The digitalization trend extends to products beyond wearables, with products such as smart tennis racquets, smart water bottles even smart umbrellas, there is a distinct trend towards more commonly used products incorporating electronic components. This digitalization parallels intelligent hardware facilitated and driven by the IoT. The consequence of this trend is that products containing electronics will be even more diffuse and at the end-of-life, CRMs even more dissipated in the urban mine.

The five trends described can be succinctly illustrated by the evolution of the mobile phone, from a simple analogue portable phone to the devices on the market with high-end computing functionality. Table 3 below provides a glimpse of how mobile phones became smaller, smarter, mass-market products from expensive business devices that are no longer only for voice communication.

Table 3: Mobile phones as a case study of product trends over the past 70 years.

Year of Introduction		Component composition
1949 	Introduction of the '0G' porTable phones in the US. AT&T launched the "Mobile Telephone Service"; Restricted service to just 40,000 customers; Customers waiting 30 minutes or more to place a call	Electro mechanical components; analogue technology with little electronics
1979 	1G Cellular Networks first deployed in Tokyo using automated cellular technology; Launched in Europe in 1981 in Sweden, Norway, Finland and Denmark. Larger call volume, quicker connection. Left: Nokia model from 1982. Weight 9800 g (https://nokiamuseum.info/category/launching-year/1982/)	Keypads instead of diallers; start of miniaturisation
1990s 	2G cellular networks launched. Technology shift from analogue to digital transmission that came with advantages like better security, faster networking, advanced mobility i.e. roaming, and larger call volume. Introduction of basic SMS communication. The world's first SMS text message was sent in Finland in 1993. Introduction of 'candy-bar' phone design. Left: Nokia model from 1990. Weight 500g (https://nokiamuseum.info/nokia-pt612/)	Monochrome LCD display, memory
2001  	3G network launched in Japan. High speed data transfer capability meant ability to access internet through the phone; phones with greater computing power, memory storage, multiple functionalities, smaller size. Left-top: Nokia model from 2001. Weight 88g (https://nokiamuseum.info/nokia-6500/) Left – bottom: iPhone model from 2007. Weight 135g	Integrated FM radio, Li-on batteries, larger back-lit and colour LCD displays; touchscreen; cameras; built-in sensors for orientation, ambient light, GPS etc; Wi-Fi and Bluetooth communication modules

2009 	4G network launched in Stockholm and Oslo which provides high speed mobile web access, IP telephony, high-definition mobile TV capabilities etc. Left: First 4G compatible phone from Samsung. Weight 131g	Large, brighter touch screens with AMOLED displays, dual cameras, high speed processors, chipsets, RAM, graphics processing chip, sensors such as barometer, compass
20XX (future date unknown)	5G will support higher density of mobile broadband users, supporting device-to-device IOT and lower battery consumption.	Potentially embedded in touch sensitive jackets, gesture sensitive interface etc.

2.2 EEE Data Availability and Estimation Approach

For new and upcoming products and product categories, data on the weight, composition, stocks, flows, lifespan etc., the essential building blocks for any estimation or forecasting of material demand at the critical raw material level, is incredibly and understandably hard to come by.

The screening of sources, including patent databases, trade and industry journals, academic publications, expert blogs, news and media articles etc. revealed little by way of concrete data for many products in the hype cycle, for example drones or wearables etc. The approach was to consider product diffusion curves (e.g. Bass Diffusion) of previously adopted products, and based on similar product, market, functional and other characteristics, make estimations of the market demand for the product, its adoption curve as well as some lifecycle estimates. Based on scenarios of likely adoption rates and product lifespan estimates, both at a sub-component as well as for a few sample products, an estimation of the material demand in the near future for the upcoming technologies and products can then be made.

2.2.1 Bass Diffusion Model

The spread of an innovation in a market is termed "diffusion". Diffusion research seeks to understand the spread of innovations by modelling their entire life cycle from the perspective of communication and consumer interactions. The adoption of consumer durables is most widely researched in diffusion models, popularized in the marketing literature with the seminal article by Bass (1969). In his paper, building on theoretical concepts presented by Rogers (1962), Bass presented a growth model for the timing of initial purchases of new products suggesting that new technologies are not adopted immediately by all the potential buyers, but rather a diffusion process is set in motion in which there are largely two groups of adopters, the innovators and the imitators.

Diffusion models have been particularly useful in providing frameworks for understanding the processes by which new products come into circulation and spread across populations of adopters. The literature indicates that the predominant application of diffusion models has been for purposes of forecasting the trajectory of new product adoption, for newly introduced products as well as for products to be introduced that are similar in some way to existing products whose diffusion history is known (Lilien, Rangaswamy and van der Bulte, 1999).

The Bass Diffusion Model (BDM) has a behavioural rationale that is consistent with studies in social science literature on the adoption and diffusion of innovations (Norton and Bass, 1987). The difference among individuals in their response to the new ideas is called their innovativeness: the degree to which an individual is relatively early or late in adopting a new product or idea.

In the BDM, sales of a product are driven by innovative or imitative demand, with the important distinction between an innovator and an imitator being the buying influence. Imitators adopt based on positive word of mouth influences from current adopters, while innovators need no such special impetus. Over a large number of new products and technological innovations, the BDM describes the empirical adoption curve quite well. In the BDM, the cumulative adoption of a consumer durable follows an S-shaped logistic curve, as sales of a product are driven initially by innovative demand followed by imitative demand until the market potential, or saturation is reached. Thus, the cumulative adoption function is given by:

$$F(t) = \frac{1-e^{-(p+q)t}}{1+\frac{q}{p}e^{-(p+q)t}} \tag{1}$$

And the density function for the fraction of the total market potential that adopts a product at time t is given by the equation:

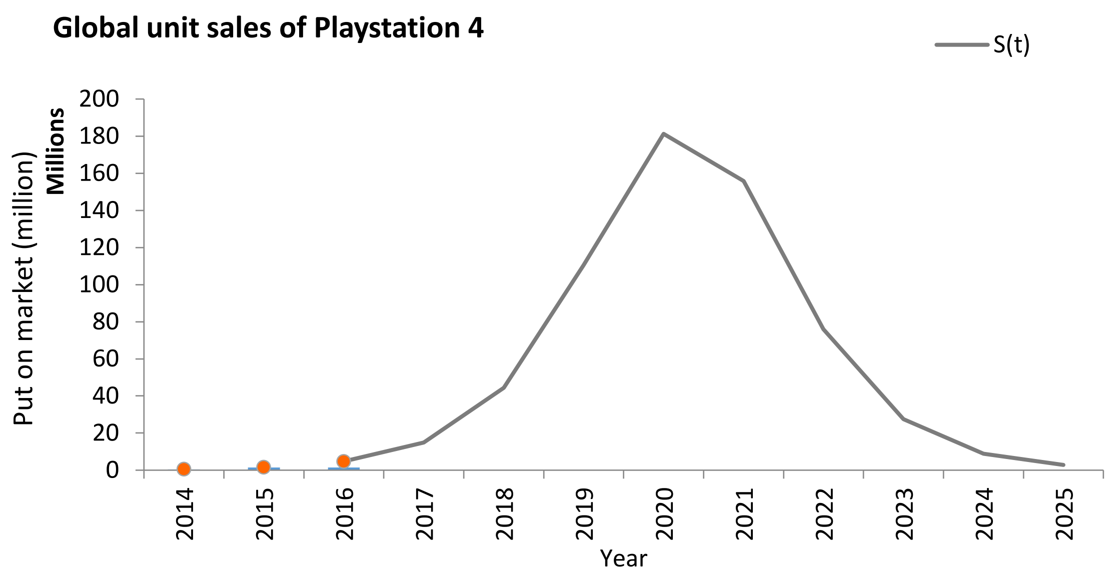
$$f(t) = \frac{(p+q)^2}{p} \frac{e^{-(p+q)t}}{\left(1+\frac{q}{p}e^{-(p+q)t}\right)^2} \tag{2}$$

Here parameters p and q are the ‘coefficient of innovation’ and the ‘coefficient of imitation’, respectively. The coefficient p, considered exogenous, captures the influence on potential adopters’ decisions that is independent of the existing number of adopters, i.e. the influence that is not obtained through interpersonal (word-of-mouth) communication with existing adopters. The coefficient q on the other hand, is endogenous, and measures the influence of existing number of adopters on purchase decisions of other people yet to adopt the new product.

Sales at time t are given by the equation:

$$s(t) = mf(t) \tag{3}$$

Here m is the total market potential. As an example, global unit sales of the game console Playstation 4, Figures 15 and 16, by Sony provides an illustration of the diffusion of product into the market. In this case, the parameters of the Bass Diffusion are *p, q, m*.



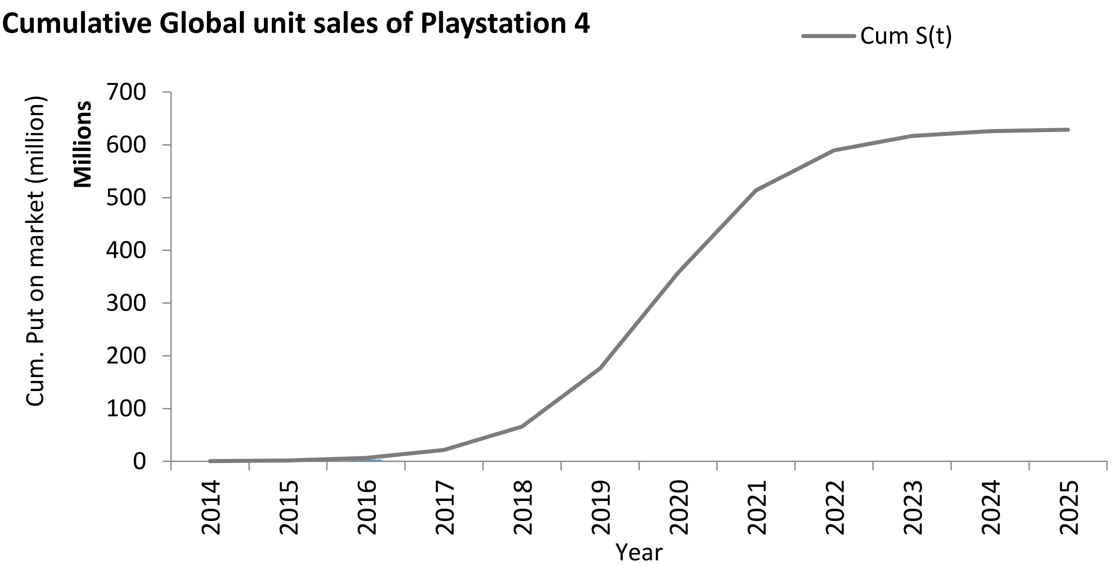


Figure 15 & Figure 16: Diffusion of Playstation 4 Game Console

One of the important benefits of the Bass model is for forecasting the diffusion of a focal product by using the parameters of the diffusion process for analogous products.

2.2.2 Estimating the Bass Model Parameters

Therefore, a diffusion model produces a life-cycle sales curve based on a small number of parameters. The parameters may be estimated:

- By analogy to the histories of similar new products introduced in the past;
- From ownership surveys or early sales data if the product has been recently introduced; and
- Linear and nonlinear regression can be used where there is historical sales data for the new product for a few periods (years).

Given at least four observations of N(t), nonlinear regression can be used to estimate parameter values (N,p,q) to minimize the sum of squared errors. An important advantage of this approach is that users need not know when the product was introduced into the market. They only need to know the cumulative sales of the product for the estimation periods.

2.2.3 Using Bass Model Estimates for Forecasting

Once the parameter values have been determined by estimating or by using analogies, these values can be used to develop forecasts by directly selecting p and q from analogous products. In applying the BDM, especially in forecasting contexts, it is important to recognize its limitations. Most past data (from analogous products) describe how successful innovations have diffused through the population, but do not account for their chances of success. While the use of analogous products can help make forecasts about innovations entering the market, the choice of a suitable analogous product is critical and requires careful judgment.

2.2.4 Data Availability and Challenges

Sales volumes of products put on market are often available for many products, some at a global level only and some at a country level. For EEE products, product categories and types launched in more recent years can provide time-series data from the time of introduction into the market, which in turn provides an excellent basis to estimate the diffusion parameters described above. An example of such a product is the smart phone which was introduced in 2007 and which shows, in Figure 17, a clear cumulative sales S-curve. However, the sales data does not identify whether the sale was to a new adopter or an existing smartphone user replacing a device. For some products, brand level sales data may be more easily available, for example PlayStation 4 Game consoles (Figures 15 & 16 above) rather than game console sales in total, or iPhone sales instead of mobile phone sales in total. However, a brand, even if dominant, is only a part of the market, and any estimate based only on the market of a brand may result in market-size distortion, especially when estimating market potential.

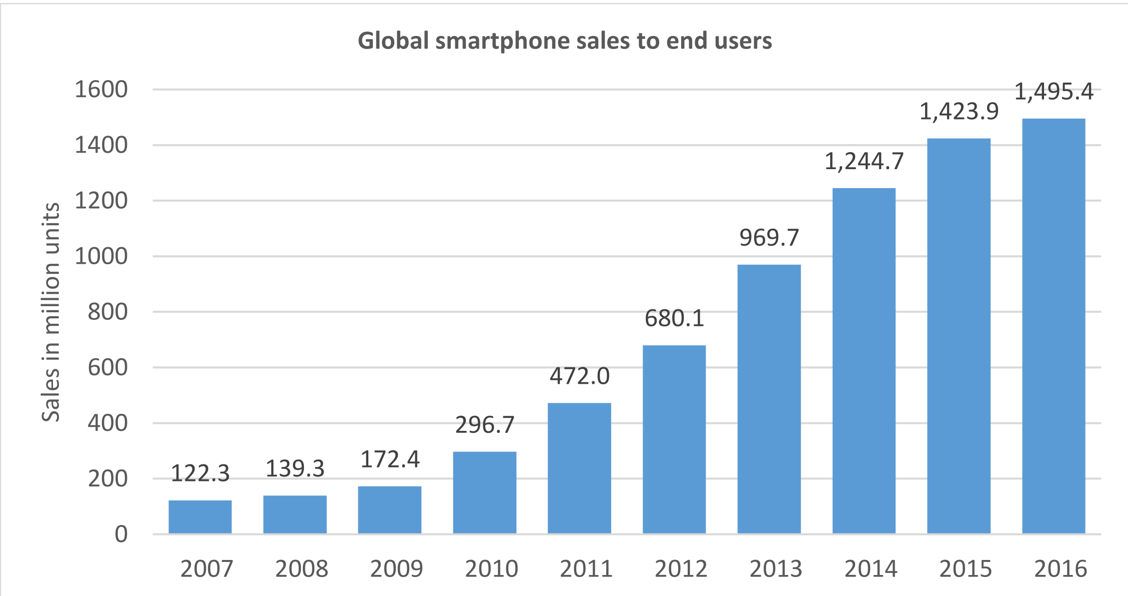


Figure 17: Diffusion and adoption of smartphones. Source: Gartner and Statista

For product and product categories that are already mature and have reached market saturation, sales data from the time the product was introduced to the market may not often be available. For example, refrigerators were introduced nearly 100 years ago, and little or no sales data regarding their diffusion into the market exists. The societal stock of TVs in Switzerland can be estimated (Khetriwal, 2012), from the time TVs were introduced in 1950 by estimating and reconstructing product adoption in the early years, shown in Figure 18. An additional challenge for some mature products is that there is often more than one product per individual or per household as households have more than one TV or individuals have more than one phone. Product ownership data can be especially useful where sales data are not available, especially to estimate the market potential of an existing product.

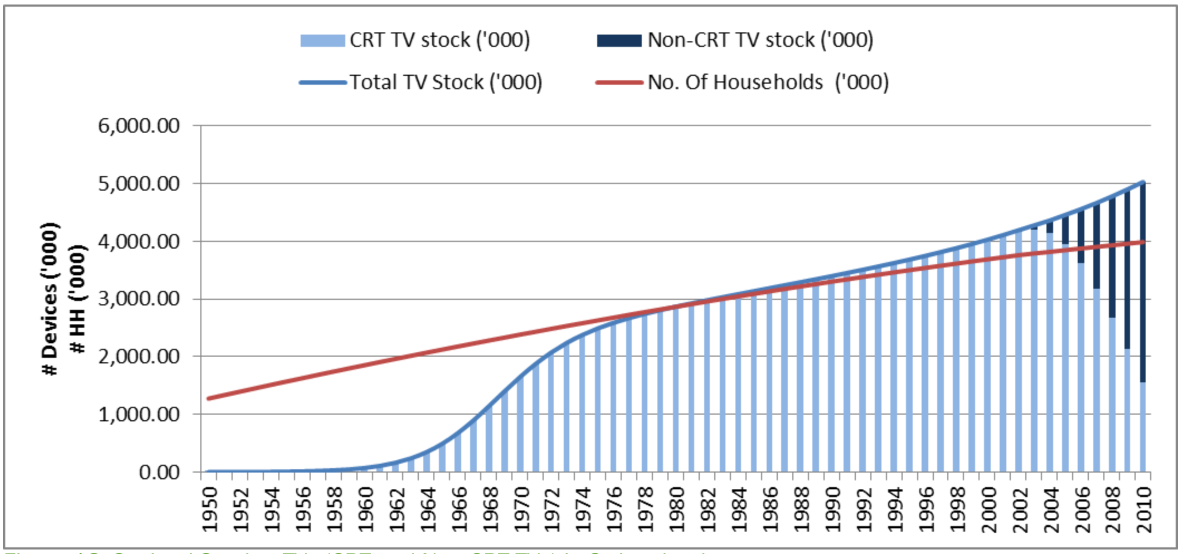


Figure 18: Societal Stock – TVs (CRT and Non-CRT TVs) in Switzerland

2.2.5 Identifying Analogous or Reference Products

Products that have similar functionality, for example LCD TVs and OLED TVs which fulfil the same functionality and market adoption of as each other can be considered analogous to the other. Products that target specific market segments or users, for example, VR headsets, may have similar diffusion characteristics and market size as game consoles as they target similar users.

For durable goods that are more expensive, an indicator for an analogous product may be the ratio of price to average income, especially as the barrier to greater market adoption may be the price. In this sense, large screen LED TVs may be analogous to smart refrigerators as they were both replacing existing products in a mature product category, and have a high entry level price at the time of introduction which falls over time. This is shown in Table 4 below.

Table 4: WEEE Category, product, analogous product and data availability

WEEE Category	Focal Product	Analogous Product	Data availability of diffusion parameters
1. Temperature exchange equipment	Smart refrigerator	LCD TVs >> high value consumer durable similar to refrigerators. Product adoption at a household level	LCD TV adoption in Switzerland
2. Screens, monitors	OLED screens	LCD TVs	LCD TV adoption in Switzerland
5. Small equipment	Personal robots	Robot vacuum cleaners	
6. Small IT and telecommunication equipment	VR headset	Game consoles	Playstation 4

2.3 Forecasting CRM Parameters in EEE

2.3.1 EEE Functional Component Trends

Forecasting actual trends and the effect on CRM parameters and attempts to produce tangible data for individual products is extremely difficult. However, what can be concluded upon is the type of functionality demand versus the type of components that will be used for this. Figure 19 illustrates what are, more or less, common functions in many products. This convergence in functionality provides an opportunity to look at components, rather than products to allow a better estimation and understanding of the demand for raw materials by looking at a limited set of sub-components rather than a much larger set of products. However, it means that components with critical raw materials will be ever more dispersed across many more products.

Connectivity and communication play an important role in the new and upcoming products, see Figure 19. Even small domestic appliances have electronic components and modules for Wi-Fi connectivity with devices such as vacuum cleaners, electric toothbrushes, bathroom scales, fully automatic coffee machines and multi-cookers that can now be controlled via smartphones or Tablets.

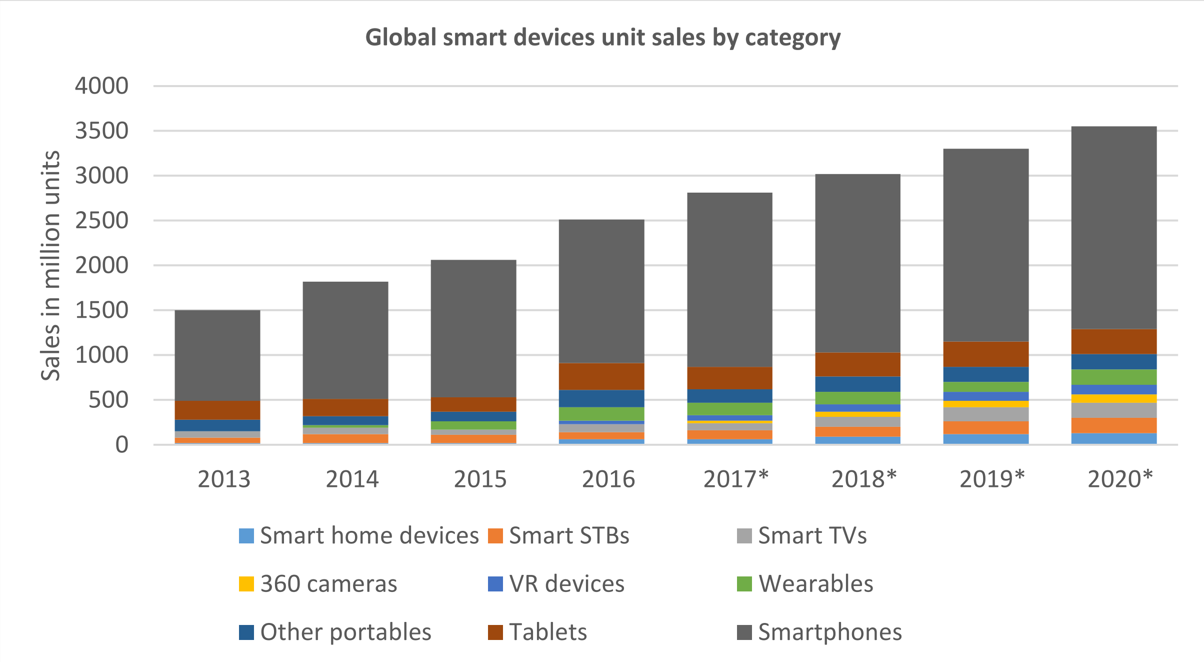


Figure 19: Demand for communication and connectivity modules in consumer electronics. Source: Ovum and Statista

On a product level, there is a big push towards mobility and portability. This is for large and small devices, including products from autonomous cars, e-bikes, hoverboards and delivery drones to laptops, mobiles, e-books etc. These are driving the demand for mobile power, and in turn at the component level demand for various battery modules.

As products come with multiple functionalities, they often have multiple sensors at the component level to provide such functionality. Micro-electro mechanical sensors (MEMS) have proliferated into devices especially due to the trend for miniaturization described earlier.

Human interface technologies for display, input and output have advanced rapidly, and devices increasingly come with functionalities such as voice activation, touch screens, gesture control etc. See Figure 20 and Table 5.

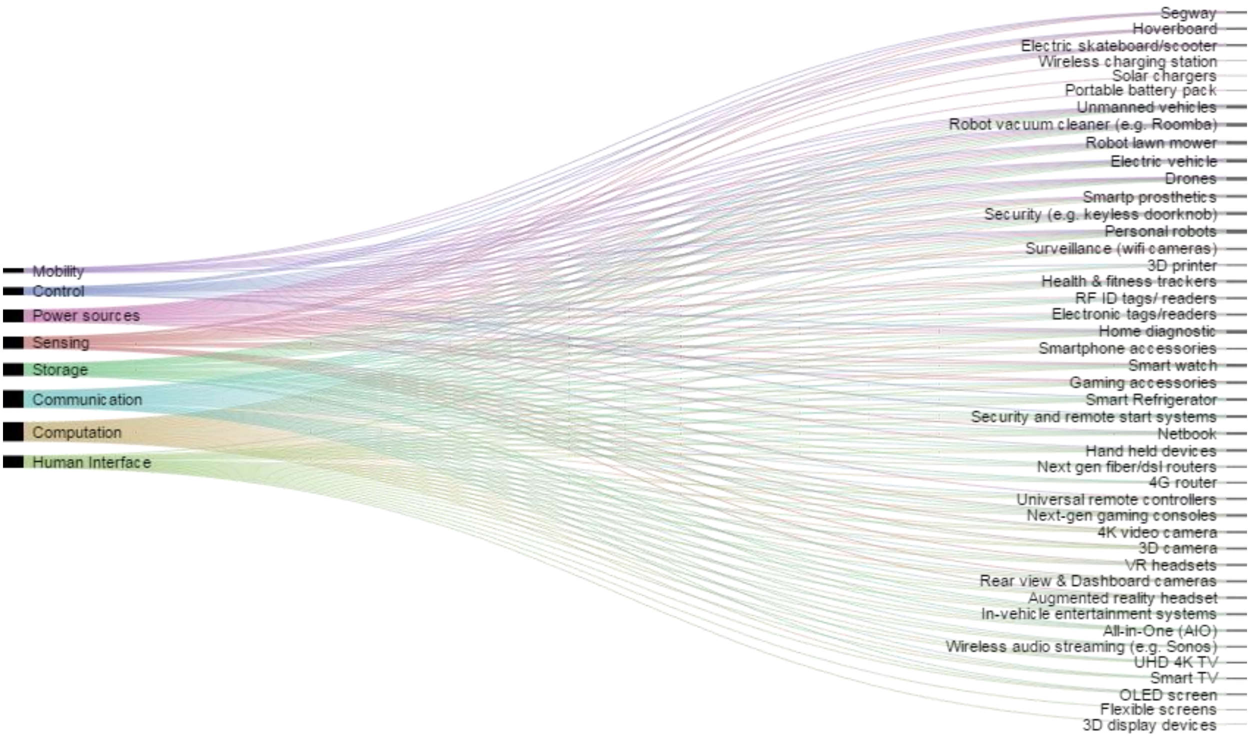


Figure 20: Component use in new products

Figure 20 above is a visual representation of the sub-systems and components which are used to achieve these different functionalities. Table 5 shows the relationship with components in more detail.

Table 5: Component use in new products

Sub-systems	Component level
Power sources	Photovoltaic Battery Lead Acid NiMH Fuel cell Wireless charging
Sensing	Environment parameters Body kinetics Health parameters Location
Human Interface	Display device Speaker Microphone Camera Touch interface
Mobility	Aerial mobility modules Ground mobility modules Underwater mobility modules
Communication	WiFi LTE/4G Fiber optic NFC Wired BlueTooth LAN ZigBee Z-Wave

Sub-systems	Component level
Computation	Low power CPU Graphics processing
Storage	Solid state Cloud based

As an example, a typical bill of materials for a modern smart phone has all of the above components: from human interface, to computing and storage, to sensors and communications as shown in Table 6 and Figure 21.

Table 6: Typical component use in smartphones

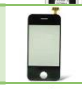
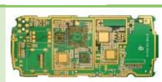
Camera Module		**Human interface**
Touch Panel		Human interface
Battery		Power source
HDI PCB		Computation
Gyro/Accelerometer		Sensor
LCD driver IC		Control
Digital Compass		Sensor
MEMS Microphone and speaker		Human interface
Audio Codecs		Human interface
NAND Flash (16GB)		Storage
Applications Processor		Control
Baseband		Communication
Touch Screen Display		Human interface
DRAM		Computation
FEM and Misc RF		Communication
Combo-chip (WiFi, BT)		Communication
Power Management		Power source
Power Amplifier		Power source
Touch Controller		Human interface
GPS		Sensor
Image Sensors ASP		Sensor

Figure 21: Teardown showing main modules and components of a popular smartphone available in the market in 2016. Source: iFixit

2.3.2 EEE Product Trends Over Time

Building on Section 2.2.4, and based on the approach models there, this section reviews technological advancement over time by considering one UNU Key per collection category. The trend is shown as an S-curve covering the four phases of product market development, i. Introduction, ii. Growth, iii. Maturity and, iv. Recession. The ‘out of production’ phase has been included for the products which are no longer in production but were part of product development phase.

Cathode Ray Tube (CRT) televisions were phased out by the introduction of Flat Panel Display (FDP or commonly known as LCDs or Plasma) in 2004. In Figure 22, television technologies are visualized based on their panel and/or pixel technology. The rapid transition in technology led to light-weight, wide screens with more adaptive features for watching television. An LED TV is just an LCD TV that is backlit with light-emitting diodes (LEDs) instead of standard mercury containing cold-cathode fluorescent lights (or CCFLs). Organic LEDs (OLEDs) followed by Quantum Dot Technology (QLEDs) are extremely thin, light-weight and flexible displays, where each pixel lights itself up independently of the others. Newer technology either in prototype phase or introduced in market provide ultra-high definition (4K), 3D and flexible displays.

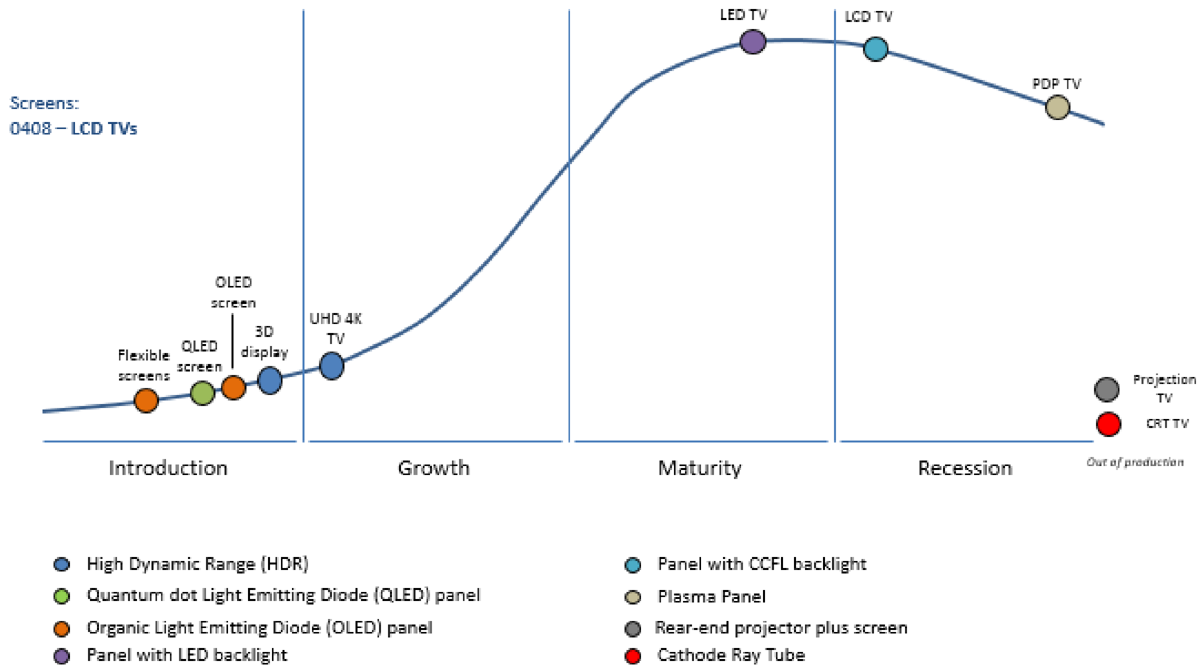


Figure 22: UNU Key 0408 LCD TVs s-curve grouped together by Panel technology

As an example, the temperature exchange equipment category, refrigerators (UNU Key 0108), is shown, given the technology shift in the use of refrigerant from CFC compressors to magnetic refrigeration (Figure 23). In 2011, the EU adopted legislation on fluorinated greenhouse gases (FCs and HFCs) framed by the Kyoto Protocol, which phased out the production of CFC compressors. However, due to their lifetime profile of 14.1 years, CFC refrigerators are still arising in waste streams. Newer refrigerator technologies are integrating touch screens, Wi-Fi and cameras inside which allows their contents to be viewed from an app and assist the user in grocery shopping.

Similarly, halogen lamps (UNU Key 0501) with tungsten filaments and compact fluorescent lamps (CFL, UNU Key 0502) both have lifetime profiles of 6.7 years. CFLs with mercury vapour inside the glass tubing are in the late majority phase followed by LED lamps. High-efficiency and low-voltage LEDs are progressively advancing to Organic LEDs (OLEDs) and Quantum dot LEDs (QLEDs) technology.

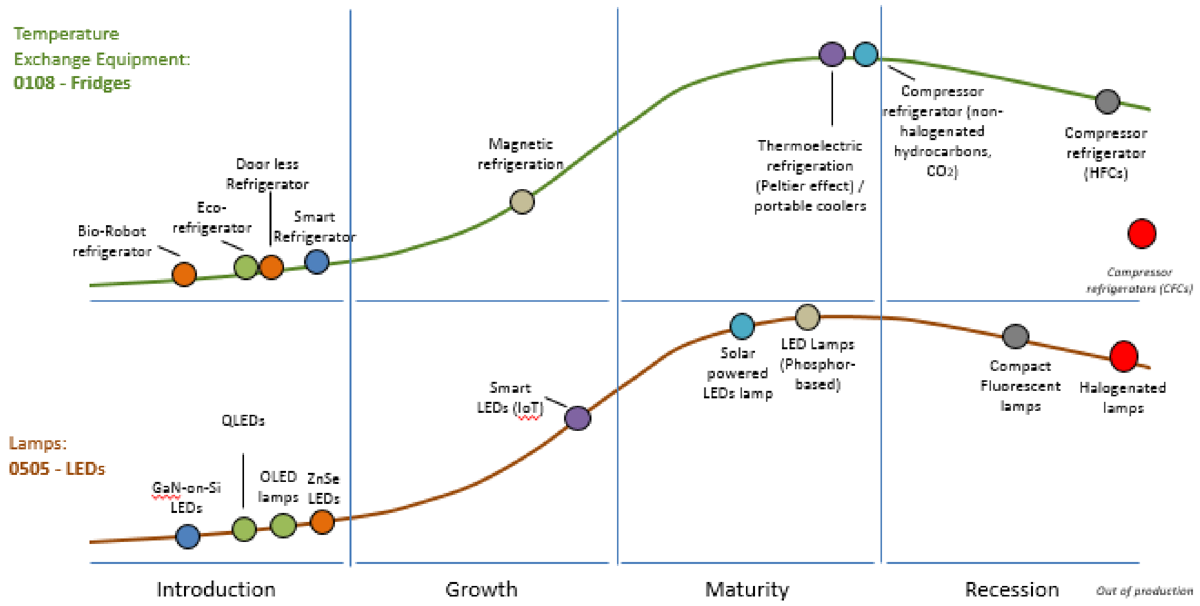


Figure 23: Product trend curve for UNU Key 0108 Fridges and 0505 LEDs

Likewise, washing machines (UNU Key 0104) have been analysed for the large equipment category (Figure 24). Top-loader washing machines (still available in Central and Eastern Europe) were largely replaced by front-loaders in the EU. Besides the widespread standard front loader washing machines, newer iterations like air-wash technology (no water, no detergent, and no drying are necessary) are being followed by intelligent washing machines with more sensors for monitoring the washing process.

Similarly, digital cameras (UNU Key 0406) are in recession and are largely replaced by digital single-lens reflex (DSLR) cameras. Digital Polaroid are GoPro eponymous action cameras are gaining maturity. Cameras are progressively advancing to high definition digital 4K video camera and 3D cameras. 3D digital cameras use two lenses to capture two images of the same scene at the same time, one through each lens. By combining these two pictures with different perspectives, the picture or video creates the illusion of depth.

Printers (UNU Key 0304) have been analysed for the small IT category (**Error! Reference source not found.**). High-volume, high-speed LaserJet printers are being trailed by 3D and wireless printers. 3D printers create a three-dimensional object in which successive layers of material are formed under computer control to create an object. 3D printers are being trailed by portable handheld 3D printers and wireless printers.

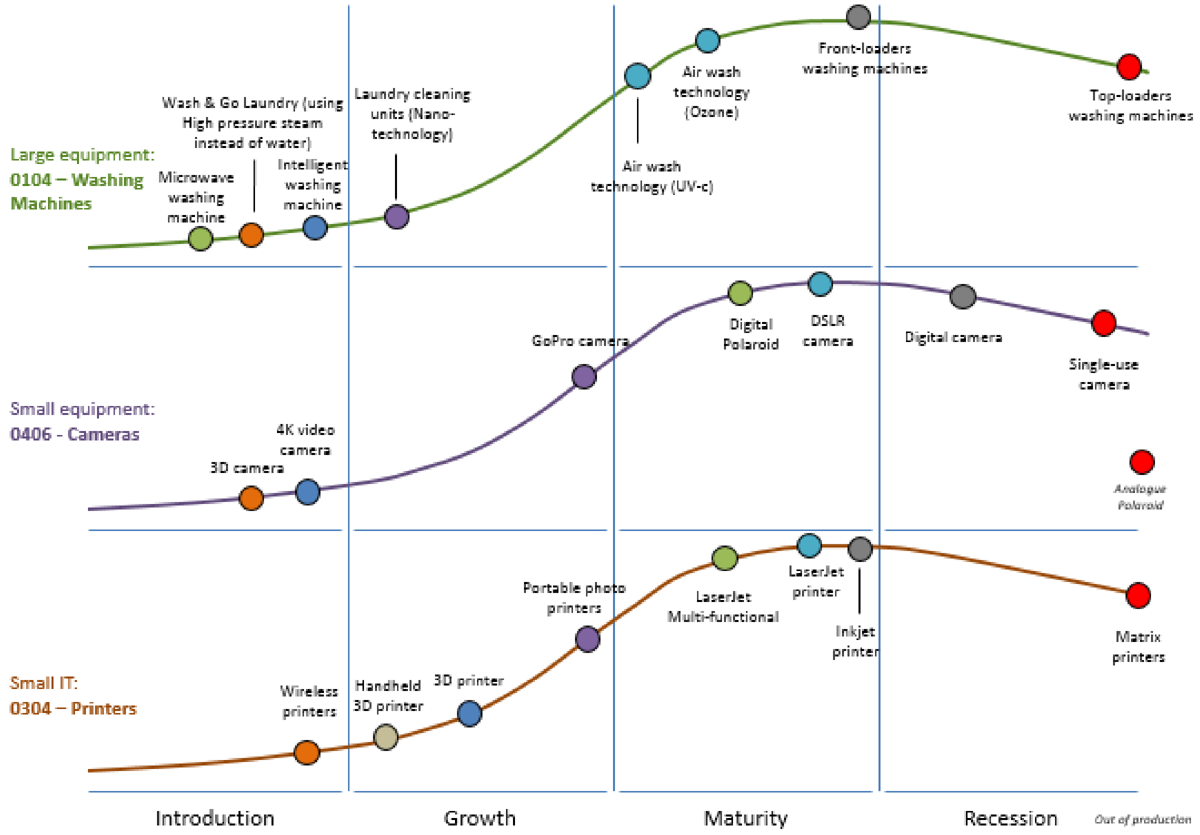


Figure 24: Product trend curve for UNU Key 0104 washing machines, 0304 Printers and 0406 Cameras

2.3.3 Contents and Trends in Electrical and Electronic Components

A questionnaire was developed and circulated to component manufacturers requesting information on CRM content and trends for components and classes of electrical and electronic components. It was sent to seven large, global manufacturers of active (integrated circuits, diodes, transistors) and passive components (resistors, capacitors, inductors, etc). Information was only provided for passive components. The active component manufacturers produce a much larger diversity of different components that did not allow them to respond to the request with reasonable efforts. The questionnaire is available in Annex 2.

Table 7 shows the results of the surveys for those passive components for which data could be obtained. The data show contents and trends for these component types. They are not representative for all passive components.

Table 7: Contents and development over time of various passive components

Component (Class)	Weight (g)	CRM	2010 Content per component	2015 Content per component	2020 Content per component	Contained in (homogeneous Material)
Type 1: Resistors, leaded, voltage dependent	0.3 - 16	Silver (mg)		1 – 75		In terminations of ceramic; in some components Ag already substituted by Cu in 2015, only few components with Ag will remain until 2020
		Silver (%)		0.3 % - 0.5 %		
		Antimony (mg)		2 – 100		As oxide in ceramic
		Antimony (%)		0.70%		
		Borates (mg)		< 0.4		As oxide in glass frits
		Borates (%)		< 0.1 %		
		Chromium (mg)		0.3 – 13		As oxide in ceramic
		Chromium (%)		0.9%		
		Cobalt (mg)		1 – 70		As oxide in ceramic
		Cobalt (%)		0.40%		
Type 2: Resistors (leaded, disks, SMD)	0.002 - 8	Silver (mg)		up to 110		Termination, solder
		Silver (%)		up to 1.4 %		
		Yttrium (mg)		up to 14		As oxide in ceramic
		Yttrium (%)		up to 0.2 %		
		Chromium (mg)		up to 2		Termination layer
		Chromium (%)		up to 0.03 %		
Type 3: Multilayer SMD Resistors, voltage dependent	0.0001 - 0.25	Silver (mg)	1 - 11	1 – 12		Inner and outer electrodes
		Silver (%)	4.4 % and more	4.8 % and more		
		Palladium (mg)	0.01 -0.8	0.003 - 0.4		Inner electrodes, for some outer electrodes as well (up to 4 mg)
		Palladium (%)	0.32 % and more	0.16% and more		
		Platinum (mg)		0.003 - 0.4		Outer electrode, only some special types
		Platinum (%)		0.16 % and more		
		Preaseodymium (mg)	0	0.02 – 2		Ceramic of special types
		Preaseodymium (%)	0%	0.8 % and more		
		Antimony		0.1 – 12		Ceramic

		(mg)		
		Antimony (%)	4.8 % and more	
		Borates (mg)	0.002 - 0.2	Ceramic, special types up to 7 mg
		Borates (%)	0.08 % - 2 %	
		Chromium (mg)	0.005 - 0.5	Ceramic
		Chromium (%)	0.2 % - 5 %	
		Cobalt (mg)	0.02 – 2	Ceramic
		Cobalt (%)	0.8 % and more	
Type 4: Multilayer SMD Resistors, voltage dependent	0.004 - 0.018	Silver (mg)	0.3 - 1.4	Inner and outer electrodes
		Silver (%)	1.7 % and more	
		Palladium (mg)	0.015 - 0.07 Inner electrode; some special types also outer electrode (up to 0,5 mg/component)	
		Palladium (%)	~ 0.39%	
		Borates		Very small portion of boroxide contained in glass fritts
		Cobalt (mg)	0.5 - 2.5	Ceramic
		Cobalt (%)	2.8 % and more	

ICT information and communication technology
SMD surface mounted device

What can be seen from the above Table 7 is the following:

For precious metals:

- All of the above passive components contain silver in terminations, and in inner and outer electrodes.
- Silver is substituted where possible by cheaper materials such as copper.
- The silver content has been and is expected to remain at the same level for those components that used and are expected to continue using silver.
- One of the four component types contains platinum with the content levels remaining stable over time.
- Some components contain palladium in inner and sometimes outer electrodes, the content is stable in one and tends to decrease in the other component type.

For rare earth elements (REE):

- Two of the four component types contain REE in ceramics, namely the heavy REE yttrium and the light REE praseodymium.
- Praseodymium was not used in this component type in 2010, but otherwise the REE content in both types of components remains stable.

For other elements:

- Three of the four component types contain cobalt in ceramics.
- The cobalt content is stable over time.
- Three of the four component types contain chromium in ceramics or in the termination layer.
- The content of chromium remains stable over time.
- Two component types contain antimony in the ceramics.
- The content of antimony remains stable over time.
- Three components contain borium/borates either in glass frits (mainly) or in ceramics.

Content levels:

- Silver, cobalt, antimony, chromium and, if present also yttrium, are contained in higher levels, even though differing over a wide range within and across the component types. Their minimum content in most cases is at least 1 mg per component and can be up to several tens of milligrams or more per component.
- The contents of borates, palladium, and platinum, if present at all, are at least one order of magnitude lower compared to the above substances.

Table 8 shows the markets and trends for the components listed in Table 7.

Table 8: Passive Component developments and trends until 2022

Component (Class)	Trends and developments until 2020 and beyond		
Type 1: Resistors, leaded, voltage dependent	a)	component sizes:	10% component volume down would be possible
	b)	component numbers:	Could be 5 to 10 % increased due protection required by various industrial standards
	c)	technological trends:	High surge performance, small size, SMD package, high operating temperature.
	d)	target markets:	Telecom and photovoltaics are hot segments
Type 2: Resistors (leaded, disks, SMD)	a)	component sizes:	Will stay constant, however 5-10 % higher average performance by products in product group "heaters"
	b)	component numbers:	Will increase by 5-10% per year in next few years due to market trends in new technologies
	c)	technological trends:	Higher break down voltage and heating power at heaters; higher break down voltage at motor start and some protection applications
	d)	target markets:	Efficient internal combustion engines, electrical vehicles, efficient inverter air conditions and motor start units
Type 3: Multilayer SMD Resistors, voltage dependent	a)	component sizes:	Appr. > 30 % volume downsizing possible to 0.2 mm x 0.1 mm or even to 0.13 mm x 0.064 mm
	b)	component numbers:	Could be 10-20% increased due to protection required by ICT, smartphone and automotive segments
	c)	technological trends:	SMD with base metal components, thin film technology on ceramic components, conductive glue termination
	d)	target markets:	Telecom, ICT and industrial and automotive growing segments

Component (Class)	Trends and developments until 2020 and beyond		
Type 4: Multilayer SMD Resistors, voltage dependent	a)	component sizes:	Appr. > 30 % volume downsizing possible to 0.2 mm x 0.1 mm or even to 0.13 mm x 0.064 mm
	b)	component numbers:	Could be 5-10 % increased due thermal requirements by industrial, smart home and automotive segments
	c)	technological trends:	SMD high accuracy stacking, use of nano-powder filled sheets, for homogeneous microstructure and tight R and B-values
	d)	target markets:	Telecom, ICT and industrial, smart home, automotive, lighting are growing segments

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SMD surface mounted device

Table 8 shows that for all four component types the miniaturization of components will continue while the number of components will increase.. While miniaturization decreases the amounts of CRM, the increasing number of components will increase the use of CRM. The ongoing miniaturization of most components in the range of 10 % to 30 % component volume reduction should therefore at least balance the 5 % to 20 % increase in component numbers in the above table. As at the same time the CRM contents in the components remain at the same level or even decrease, the total number of CRM used in these components can be expected to shrink or at least remain at the same level for the coming years. The concentration of the CRM will remain at the same level for most components. Miniaturization will, however, reduce the absolute amounts of CRM (in mg) per component. An additional effect partially overlapping with the miniaturization is increasing performance for components e.g. the type 2 resistors used in heaters. Higher performing components allow smaller components to achieve the same performance, which reduces the amounts of CRM required.

Overall, even though the component composition in Table 8 is not representative for all passive components, it is thought that there is a general trend of increasing component numbers and in parallel miniaturization of components. It can thus be expected that for passive components, miniaturization will as a minimum reduce if not fully counteract the increase of CRM use in components. A passive component manufacturer's statement confirms this expectation stating that over the past years the amounts of material used for its products has remained at the same level while at the same time the sales of components in numbers increased considerably.

2.4 Results

2.4.1 The UNU Key Catalogue

This catalogue aims to provide an overview of all UNU keys, listing the product type, key parameters (median residence time, average weight, and percentage weight share in return stream) and product specific market trends. It serves as a visual instrument where all the basic information for the UNU keys are summarized and provides sample pictures of the most common products covered under a UNU key, for example UNU Key 0303 covers laptops, tablets, notebooks and palmtops. Figure 25 shows the UNU Key displayed in the top left corner of the Figure and followed underneath by a small description of some products that correspond to it.

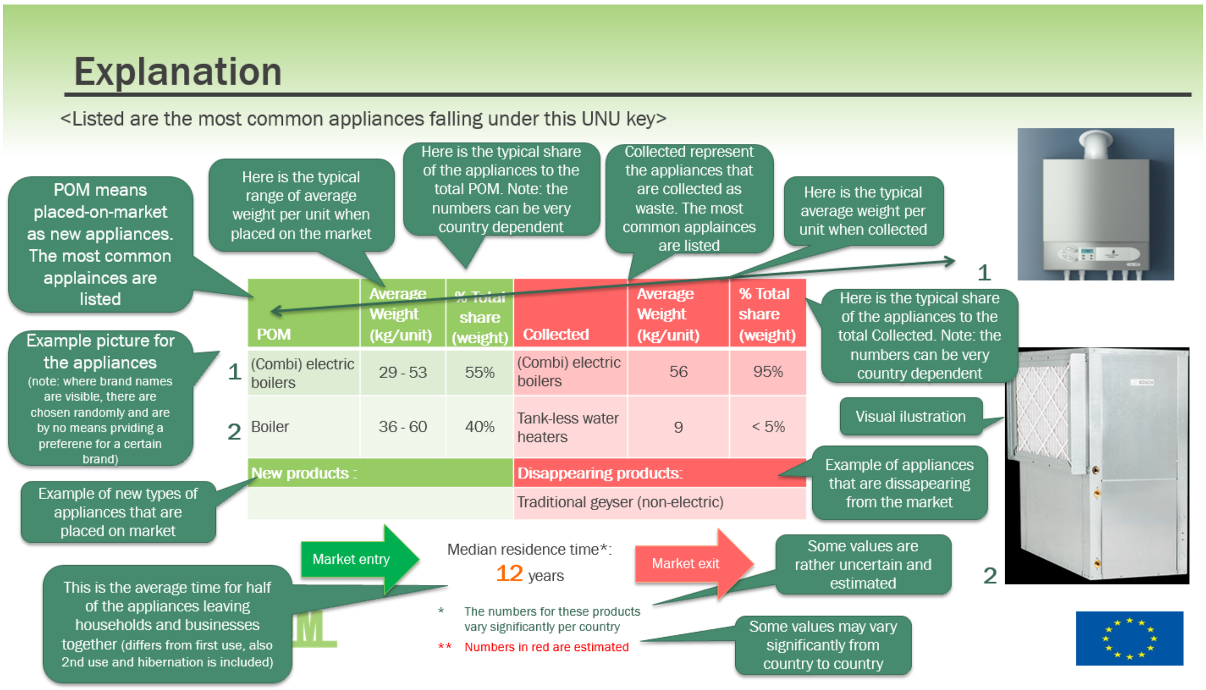


Figure 25: Description of UNU key catalogue

Below the title and list of products, the table in each slide summarizes in green on the left, vital information from the UNU Key such as the most relevant devices put on the market (POM) and their typical share of the total. The same is also presented in red on the right hand side for (older) collected products for the year 2014. It is important to add that all values in POM and the collected stream may vary from country to country, and some values indicated in red may be the result of estimates. Below the table, the median residence time for the appliances under the respective UNU key is displayed as well as certain warnings related to the parameters displayed.

New product and disappearing products are visualized with pictures in order to display product trends and evolution for each UNU Key. Examples of most products described are given and marked by their corresponding number. For a full overview of all 54 UNU keys, see Annex 1, UNU Key Catalogue.

2.4.2 Forecasting of EEE POM towards 2020

This section provides the latest data and actual EEE amounts placed on market based on the previous methodology as well as analysing the existing trends on the UNU key level. Due to the large amount of data, only one UNU Key per collection category is illustrated. The graphs below show the product, component and element trends for new technologies for all Keys except for the UNU Keys 0108 for fridges and 0408 for LCD TVs. For these two keys the effect on gold content is shown.

Category I – Temperature Exchange Equipment: Example UNU key 0108 Refrigerators

Based on the existing market input trends, the growth curves selected per collection category are shown below for three income strata. In the case of forecasting refrigerator amounts in Figure 26 from 2016-2020, it shows a 1.3% average linear growth rate for high income stratum. The middle stratum income stratum has 3.5% growth rate while the low stratum is expected to follow nil growth.

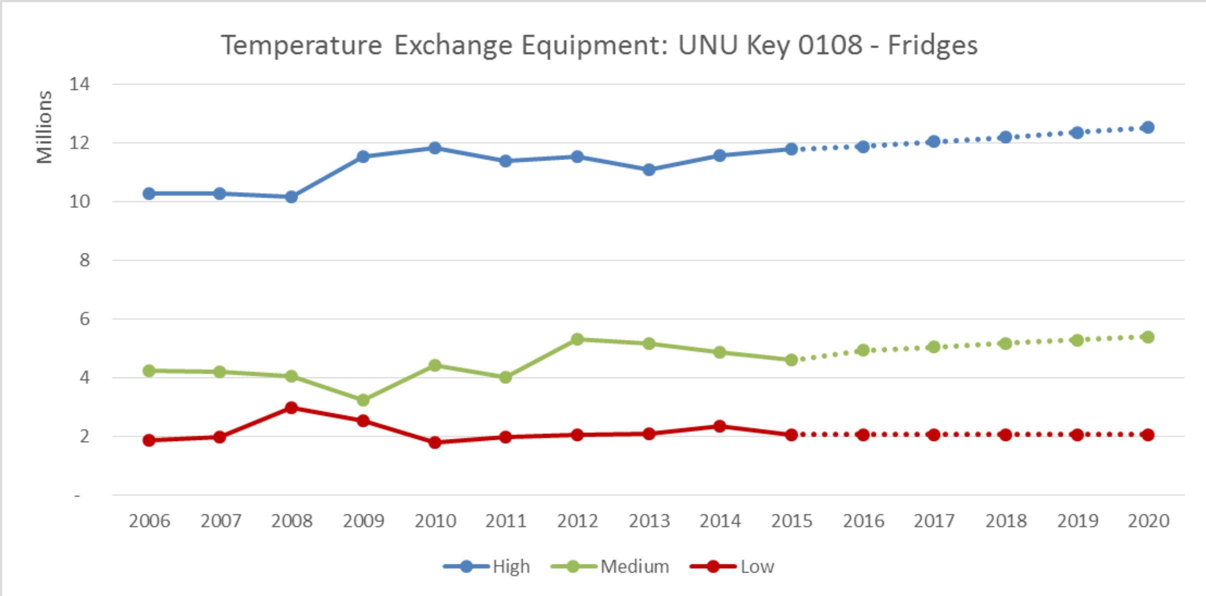


Figure 26: Forecasting of EEE POM 2016-2020 for UNU Key 0108 – Refrigerators

Based on the methodology in Section 2.2, the Bass Diffusion Curves for the reference products provide the rate of adoption of a product. This adoption factor is then applied to the existing product put-on-market trends to provide a forecast of the rate of adoption of the new technology as displayed in Figure 27.

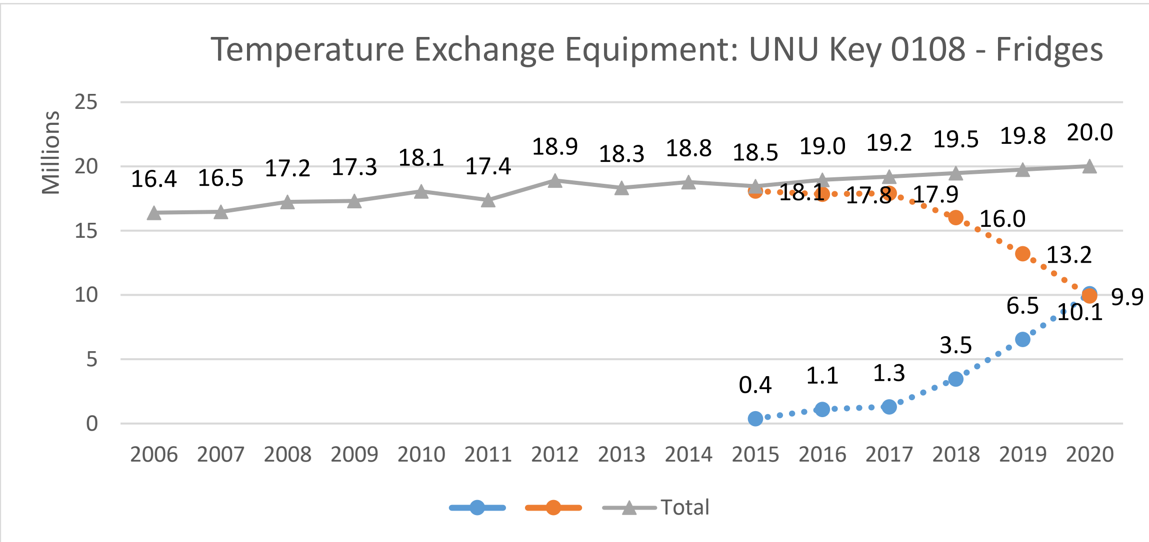


Figure 27: Adoption of smart refrigerators (blue line) vs traditional refrigerators (red line).

At a component and material level, this can be interpreted as an additional 23 million integrated screens, sensors and communication modules put onto the market in smart refrigerators by 2020 across the EU28 alone.

Category II - Screens: Example UNU key 0408 LCD TVs

Forecasting LCD TVs from 2016-2020, Figure 28, shows a 0.7% annual average growth rate for the high income stratum. The middle income stratum has a 9.3% growth rate while the low stratum is expected to follow a 9.7% growth. Between 2004 and 2008/2009 the replacement market for LCDs achieved saturation in the high stratum. Afterwards the trend is a steady decrease in the high stratum. Whilst the middle and low stratums continue to grow with an average of 9.5% illustrating a delayed technology transfer and sales of LCD TVs compared to the higher income countries in Europe.

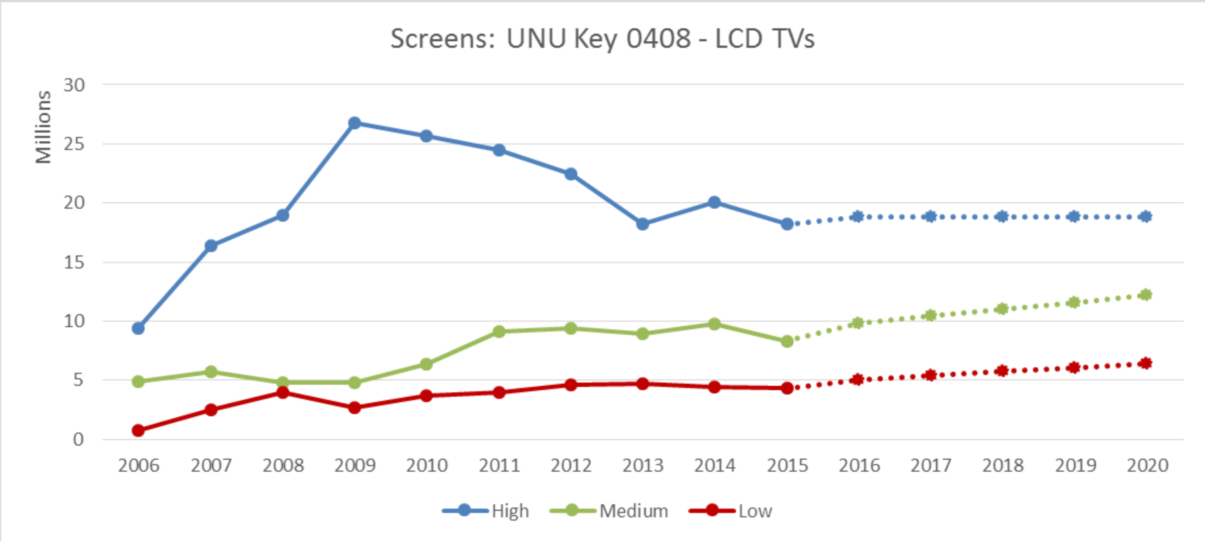


Figure 28: Forecasting of EEE POM 2016-2020 for UNU Key 0408 – LCD TVs

Again, based on the methodology in Section 2.2, the Bass Diffusion Curves for LCD TVs provide the rate of adoption of a product in Figure 29:

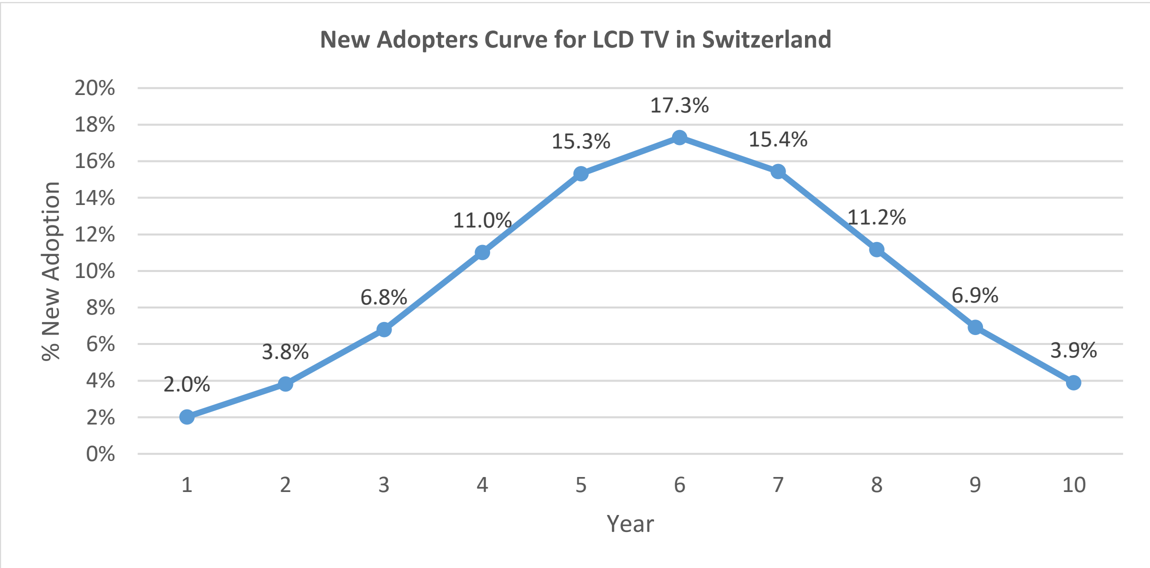
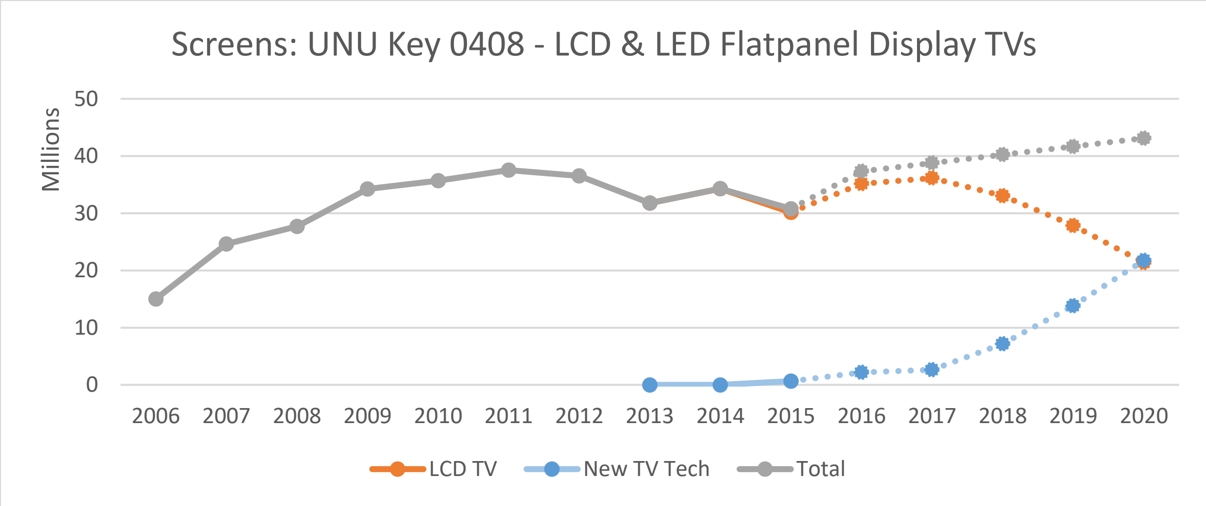


Figure 29: Adoption of LCD TVs in Switzerland.
Bass diffusion parameters p and q are 0.00016996 and 0.6914991784. Within 6 years, LCD TV sales reach half-way to market saturation.

Using the same adoption factor as a reference for the technology shift from LCD and LED TVs to OLED TVs, potentially 48 million rigid and flexible AMOLED TVs will be put on the market until 2020. At a component and material level, this has significant changes as the display technologies underlying LCDs and AMOLEDs are very different.



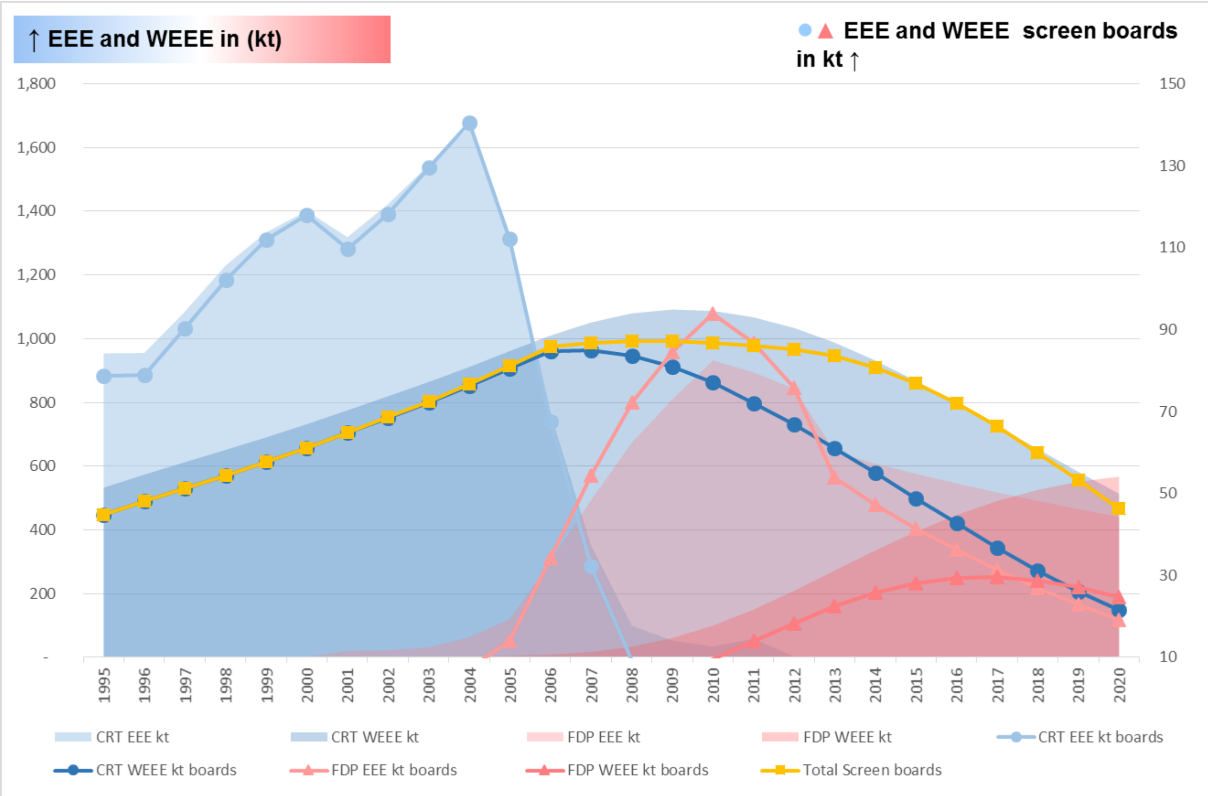


Figure 30 & Figure 31: CRTs vs FDPs put on the market and waste generation (EU28+2)

The result of the switch from CRTs to LCDs put on the market and the subsequent waste generation is displayed in Figure 31. Figure 32 shows the expected CRT vs LCD trend for 1995–2020 for the EU for all TVs in terms of printed circuit board and gold content. The surface areas represent the EEE put on the market and waste generation tonnages in kilotons, the lines represent the screen circuit boards also in kilotons. The yellow line represents the circuit board generation from all sources in kt with the right axis as the scale.

From 2004-2006, a sharp decline from 70 to 32 million units in CRTs sales and a reverse incline for LCDs occurred. From 2004 to 2014, LCD sales have almost doubled from 38 to 72 million units. Despite the high sales of lighter products with shorter lifespan (LCD TVs 9 years), miniaturization of components of the circuit boards outpace the other two effects. The net result is interestingly a rapid reduction in the volume of circuit boards from TVs which appears counter-intuitive compared to increased products sales throughout Europe compared to the CRT era.

In Figure 32, circuit board quantities are further analysed in terms of their gold content. This is based on combining the above information with the analysis of composition (over time) from Deliverable 2.5. Due to limited composition data availability, gold quantities per circuit board are kept constant for recent and future years at 0.92 mg/kg for CRT TVs and 3.2 mg/kg for FDP TVs. Here it can be observed that the ongoing miniaturization trend has a significant influence on the weight of boards generated which will also have a significant effect on the main value driver for recycling processes where the total gold content in TVs will drop markedly.

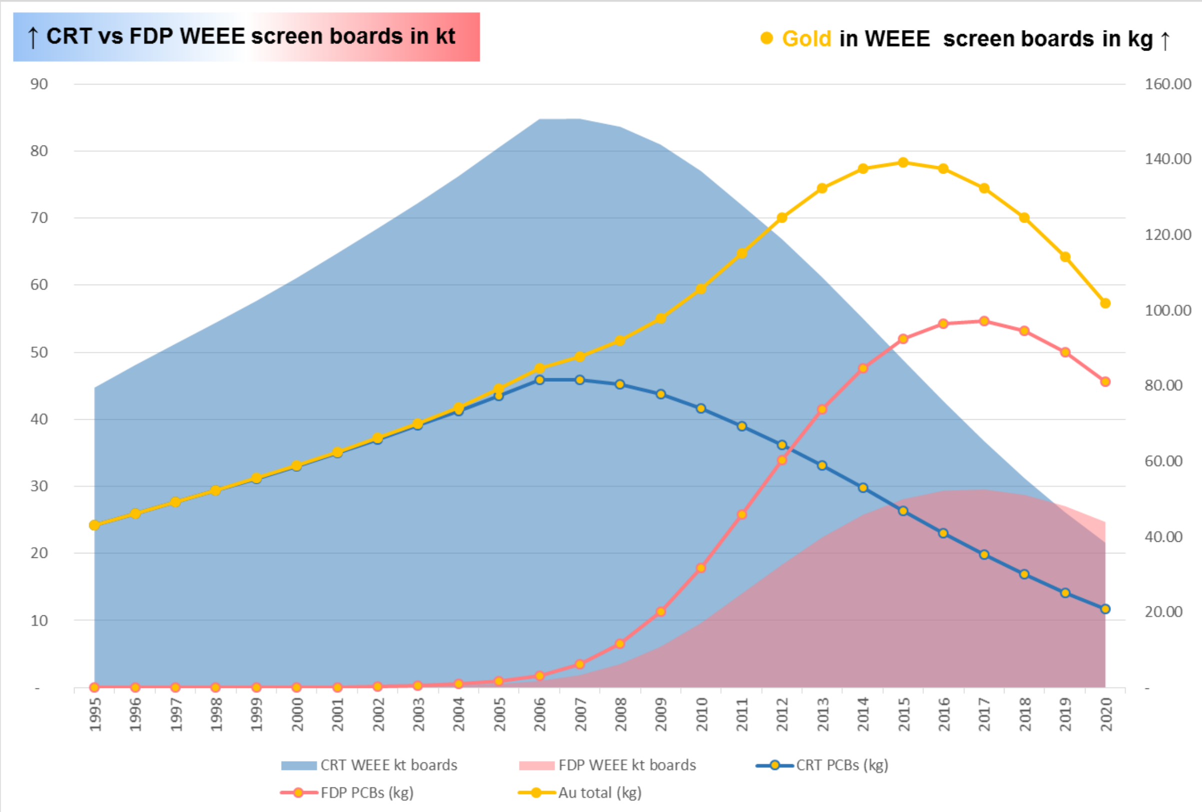


Figure 32: Gold content in printed circuit boards over time

Category III – Lamps: UNU key 0502 Compact Fluorescent Lamps

In certain cases, products may also disappear from the market. In the case of energy saving lamps like Compact Fluorescent Lamps (CFLs), the expected trend is simple for 2016-2020. It shows a rapid (non-linear) exponential decline to zero since these mercury and CRM containing lamps have been entirely replaced with low-voltage, high efficiency LEDs shown in Figure 33.

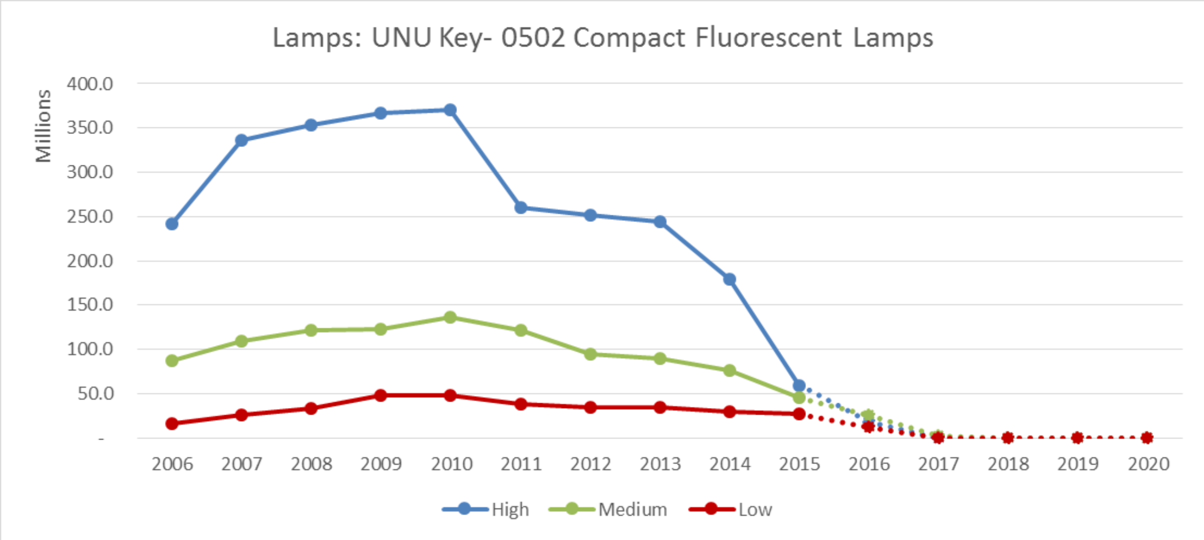


Figure 33: Forecasting of EEE POM 2016-202 0for UNU Key 0502 – Compact Fluorescent Lamps

Category IV – Large Household Appliances: UNU key 0102 Dishwashers

Similarly, forecasting for dishwashers from 2016-2020, Figure 34, shows a 2.4% average growth rate for the high stratum. The middle stratum has a 3.3% growth rate while the low stratum is expected to stay at the same level. From 2013, the replacement market for dishwashers is expanding in the high stratum. Whilst, due to rise of the middle class in the middle stratum, there is an expected growth of 3.3% in future years.

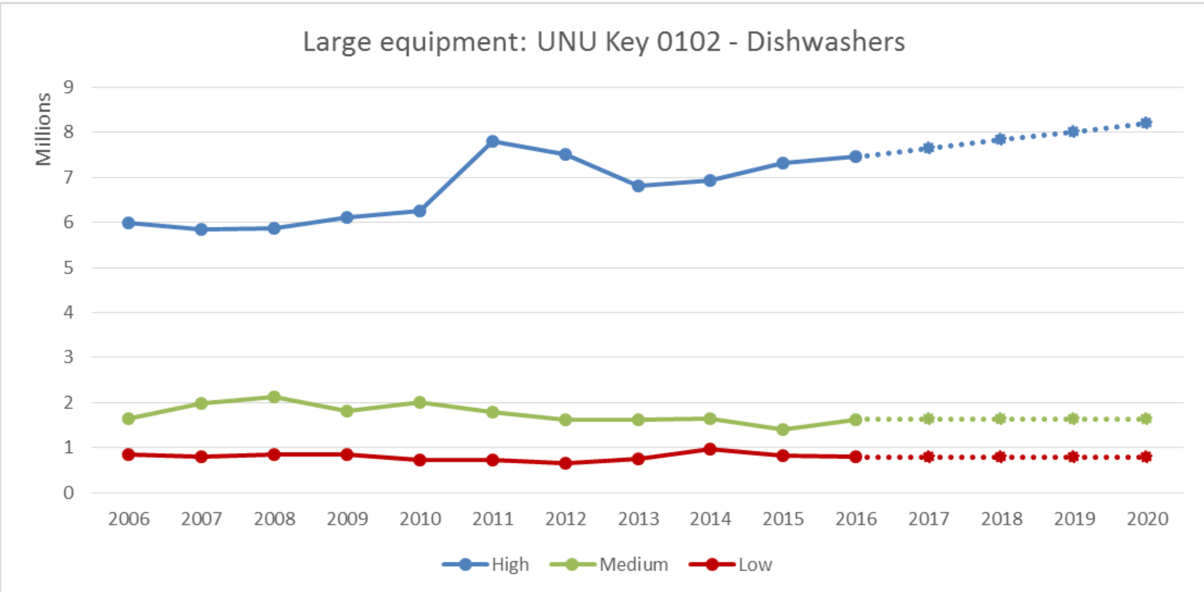


Figure 34: Forecasting of EEE POM 2016-2020 for UNU Key 0102 – Dishwashers

Category V – Small Household Appliances: UNU key 0204 Vacuum Cleaners

Likewise, the forecasting for vacuum cleaners, Figure 35, from 2016-2020 shows a 2.3% average growth rate for the high stratum. The middle stratum has a 5.7% growth rate whilst the low stratum is expected to stay the same. From 2009, the replacement market for vacuum cleaners is growing in the high stratum. A steady growth of 5.7% is foreseen in the middle stratum. Some of the growth in the high income countries is due to the increased sales of robot vacuum cleaners.

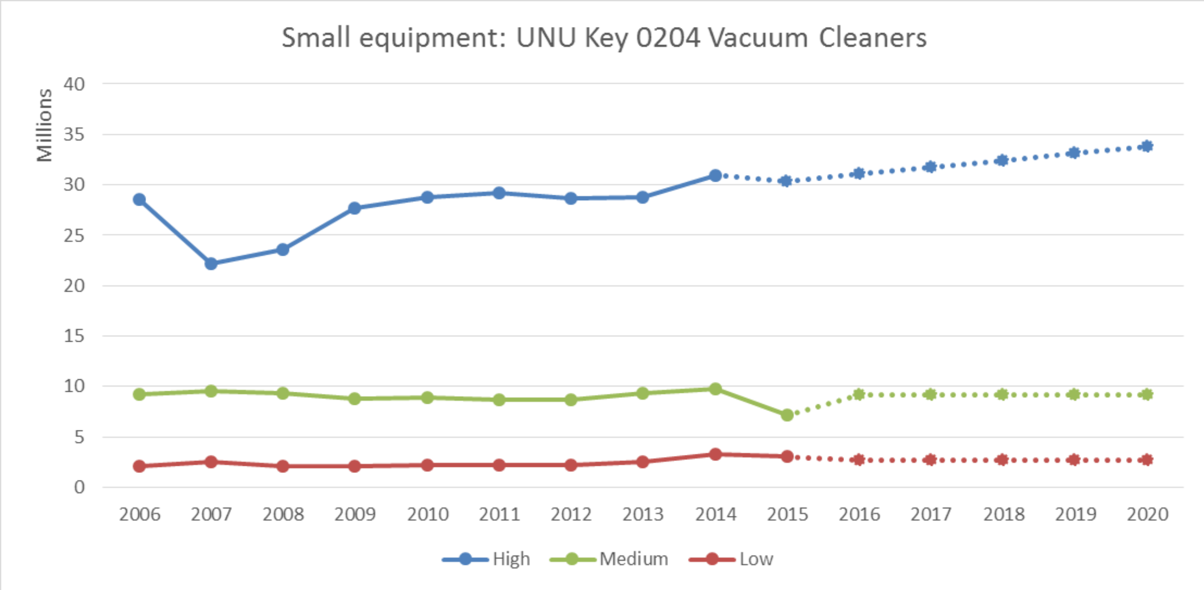


Figure 35: Forecasting of EEE POM 2016-2020 for UNU Key 0204 – Vacuum cleaners

Category VI – Small IT Appliances: UNU key 0702 Game Consoles

Interestingly, game consoles, Figure 36, show a small expected increase in sales after several years of decline due to the introduction of new models in particular in the high income stratum, followed by a 8.9% increase and a stable volume in the low income stratum.

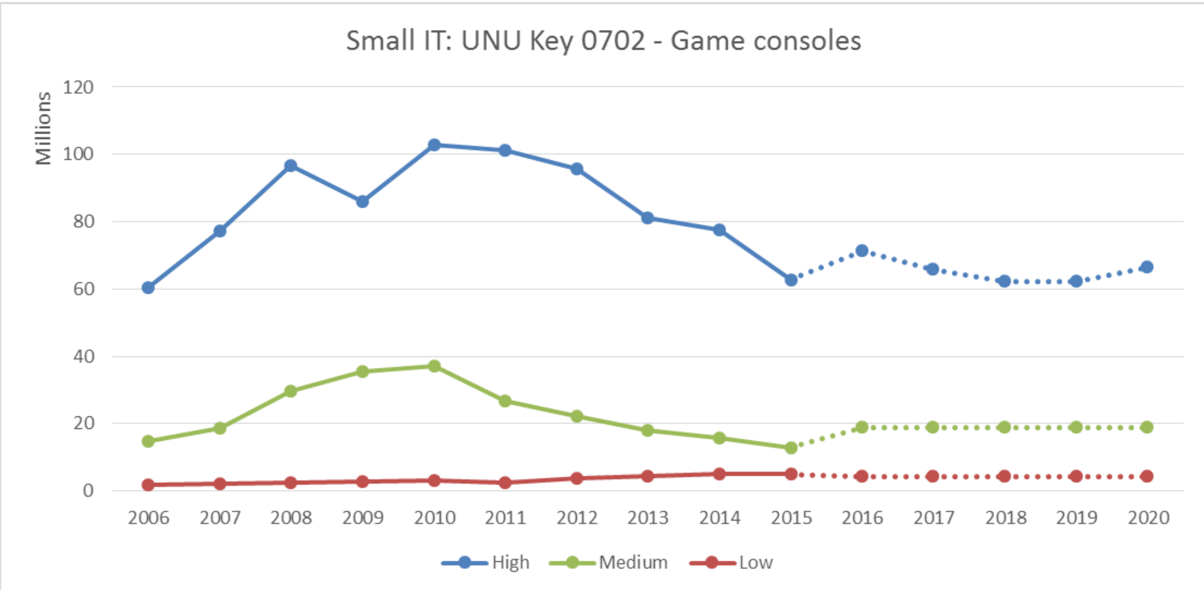


Figure 36: Forecasting of EEE POM 2016-2020 for UNU Key 0702 – Game consoles

3 Vehicles

3.1 Introduction

First and foremost, it is clear that changes have taken place both at the level of the vehicle fleet and at the individual vehicle level over time and are likely to continue doing so.

The European vehicle fleet has slowly increased in number of vehicles over a period of 15 years and amounts currently to around 250 million vehicles (see Figure 37). During the same period, the distribution over different vehicle types, e.g. the shift between petrol and diesel drivetrains, has undergone substantial changes. Currently, a shift to electrified drivetrains takes place in some member states. Such technology shifts are obvious trends, but nevertheless not the only ones. For example, a continued increase in fleet size is not inconceivable, especially considering that individual country's motorization rate, ranging from 157 to 666 vehicles per 1000 inhabitants in 2005 and from 246 to 678 in 2014 (ACEA 2017), is likely to continue to even out.

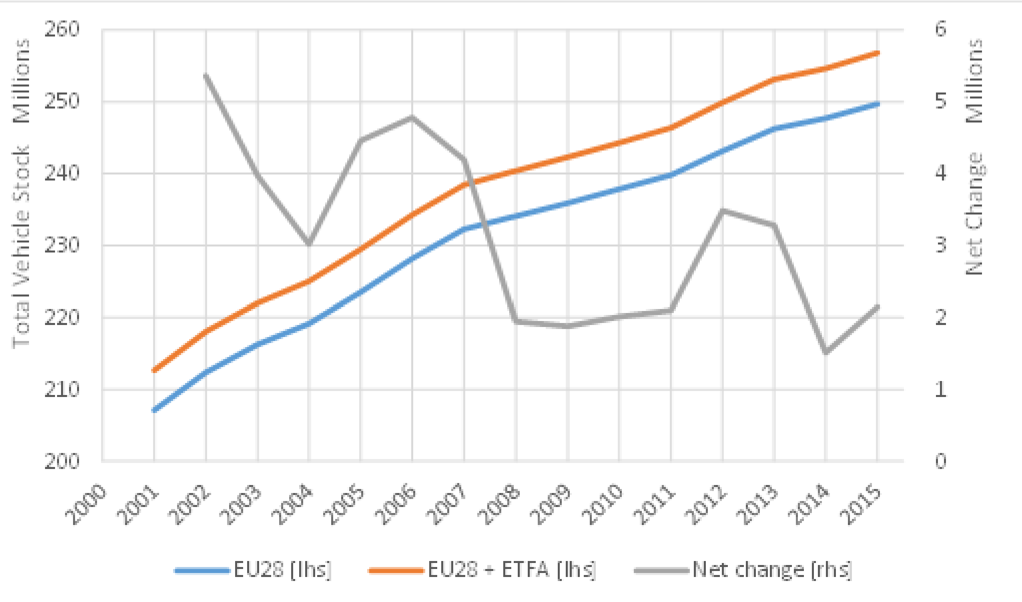


Figure 37: Total vehicle stock and net change in the EU28 and EU28+EFTA between 2001 and 2015 [million vehicles] (Eurostat).
Included are passenger cars and light commercial vehicles below 3.5 tonnes. lhs= left hand side. rhs= right hand side.

At the level of the individual vehicle, the diversity of materials has increased and new materials have been introduced as requirements have shifted and car designs and available materials have evolved. Over the years, material composition has gone from mainly wood to mainly steel and now towards a mix of various steels, aluminium, magnesium, plastics, composites and other materials (Ljunggren Söderman et al. 2013). The shift is still ongoing as is exemplified by the change in material composition of a Volvo passenger car model between 2007 and 2015 (Hamza and Trinh, 2017). Although the changes are more intricate than direct substitutions, steel and iron decreased by nearly 200 kg, while the mass of aluminium, magnesium and polymer materials increased by a similar amount.

Current vehicle trends also point at increasing variety, and in many cases increasing amounts, of CRMs, pushed by regulatory and customer driven requirements. For example, control of tail-pipe emissions with catalytic converters requires platinum group metals (PGM) and REE. The push for mass-reduction designs with materials such as high strength steels, aluminium and magnesium typically requires CRMs as alloying elements. Safety and driver assistance features, powertrain control, 'infotainment' and headlights require electronics containing e.g. gold, silver, PGM, gallium, tantalum and REE. This development is common for all vehicles, irrespective of drivetrain, but with electrified drivetrains the dependence of CRMs is reinforced as new components such as traction batteries, electric machines and power electronics introduce CRMs such as lithium, cobalt and REE.

In this chapter, selected trends are presented and discussed related to the European vehicle fleet and individual vehicle designs that are important for the composition and quantities of CRM that will eventually become available for secondary material recovery. The emphasis is on historic trends of fleets and vehicle designs, which allows for the analysis and presentation of waste generation for the coming 14 years, which is the expected median lifetime of a vehicle. Waste generated beyond this fairly predictable term, if currently observed fleet and vehicle design trends play out, is also discussed. Quantitative information on fleet and vehicle trends is presented separately where available. Quantified estimates of the total mass of CRMs in vehicle stock and flows, where fleet and vehicle trends data are combined, are not performed but will be generated as part of future work in ProSUM.

The following fleet trends are included:

1. Vehicle average mass;
2. Drivetrain distribution;
3. Engine cylinder size distribution; and
4. Age of vehicle fleet and end-of-life vehicles.

The following vehicle trends are included:

5. Steel;
6. Aluminium;
7. Magnesium;
8. Catalytic converter;
9. Electrical and electronic systems; and
10. Electric drivetrain components.

3.2 Data Availability and Estimation Approach

The data presented builds primarily on data collected and consolidated as part of the ProSUM project. Quantified estimates of the total mass of CRMs in vehicle stock and flows are not provided in this report but will be generated as part of coming work in ProSUM.

3.3 Fleet Trends

3.3.1 Vehicle Average Mass

The average mass of vehicles POM in the EU28 has exhibited a steadily increasing trend, from 1265kg in 2000 to 1385kg in 2015, corresponding to nearly 10%, and with a peak value of 1402kg in 2012, see Figure 38. Given the variance of the data, it is too early to tell if the decrease from 2012 to 2015 is a new trend. The trend in overall mass increase is however unequivocal at a fleet level.

The individual national trends in POM vehicle mass are distributed around the average, but for the most part follow the trend of the EU28 average very closely. Thus, while individual countries have their own particular vehicle mix, the overall trend towards heavier vehicles is not a national phenomenon.

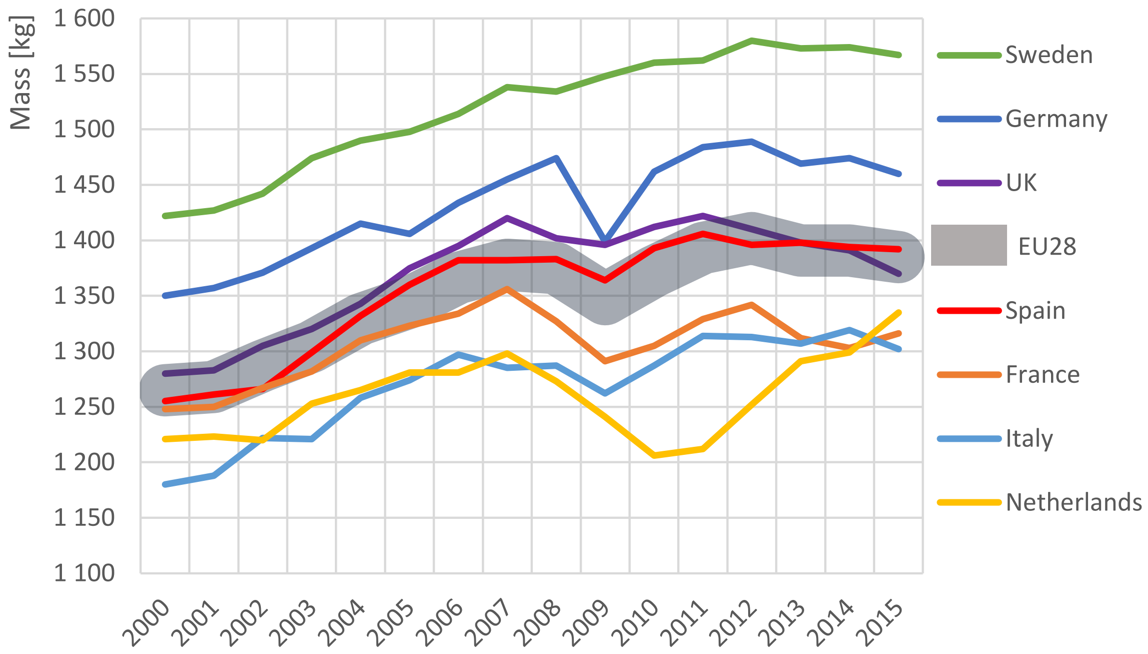


Figure 38: Mass in Running Order (MRO) of POM passenger cars [kg], EU28 average and selected vehicle markets (ICCT 2016).

3.3.2 Drivetrain distribution

Over time, the drivetrains of vehicles POM have unsurprisingly been dominated by petrol and diesel internal combustion engines (ICE), see Figure 39. There are two major changes that are visible in the data over the period from 2000 to 2015. The first is the shift from petrol to diesel drivetrains, with diesel's relative share changing from 35% in 2000 to 55% in 2011, and steady thereafter. The second major change is the growth in alternative drivetrains, see Figure 39.

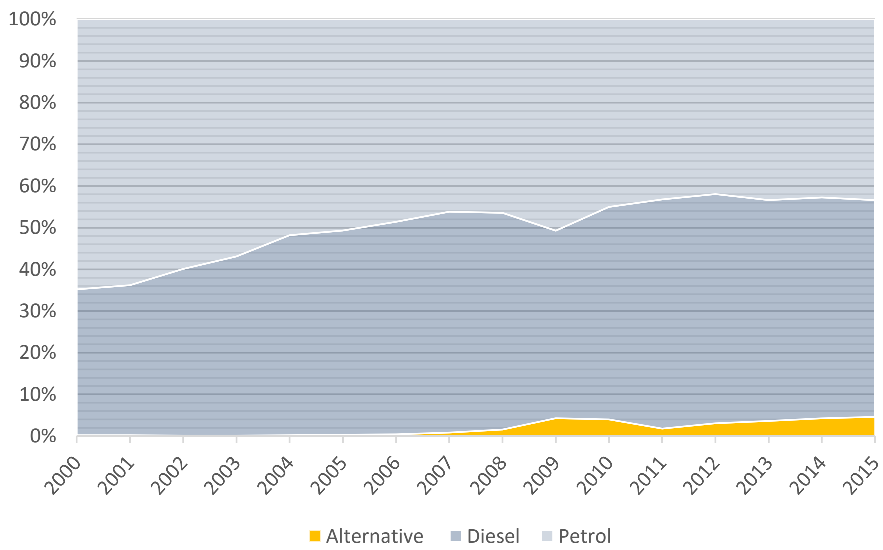


Figure 39: Drivetrain distribution of POM vehicles in EU28 between 2000 and 2015 [%] (Eurostat).

Not counting a large but brief spike in natural gas vehicles (largely Fiat vehicles sold in Italy), there is an ongoing and exponential growth in hybrid (HEV), plug-in hybrid (PHEV) and full battery vehicles (BEV) put on market, reaching 3.1% of all vehicles in 2015 and set to continue gaining in share, see Figure 40. While these vehicles are still a small fraction of POM, and a vanishingly small component of the total stock, they are very likely to play an increasingly major role in the future.

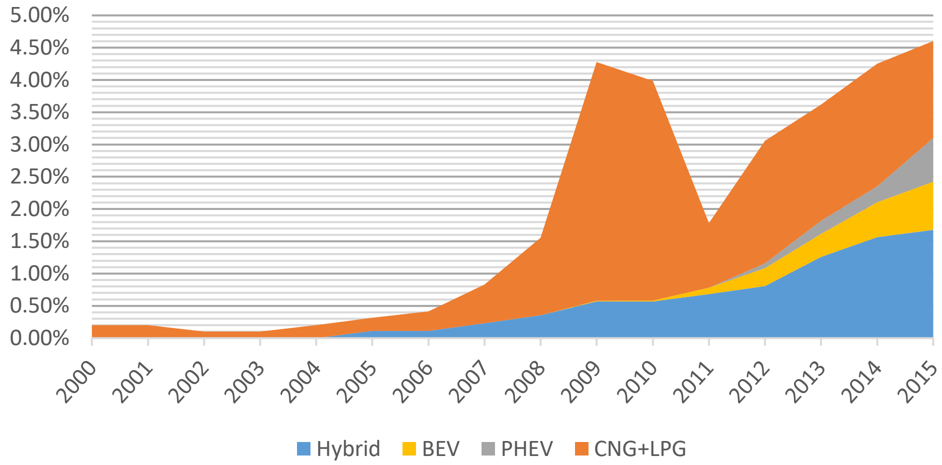


Figure 40: Alternative (electrics+natural gas) drivetrain distribution of POM vehicles in EU28 between 2000 and 2015 [%] (Eurostat, ICCT 2016).

The adoption of electric vehicles is thus far highly nationally concentrated, see Figures 41 and 42, which depict cumulative sales of BEVs and PHEVs over the last decade. The top five nations for cumulative sales represent 80% of BEVs and 90% of PHEVs sold, with France and Norway representing half of all BEVs sold in the EU, and the Netherlands accounting for almost 60% of all PHEVs sold. It is impossible to say how long and where this trend will continue as the effective price of operating a BEV or PHEV is highly dependent on local incentives and subsidies, which can change on very short notice.

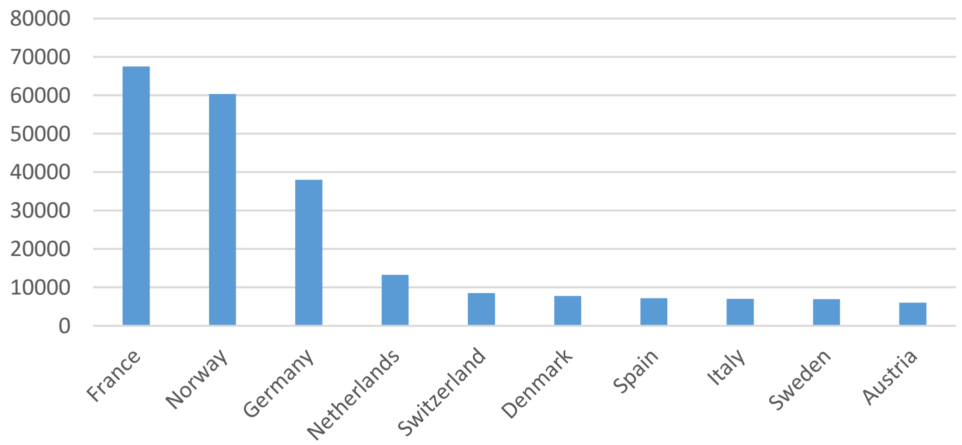


Figure 41: Cumulative BEV sales between 2006 and the end of 2015, TOP 10 countries in EU28 [number of vehicles] (Irle 2016).

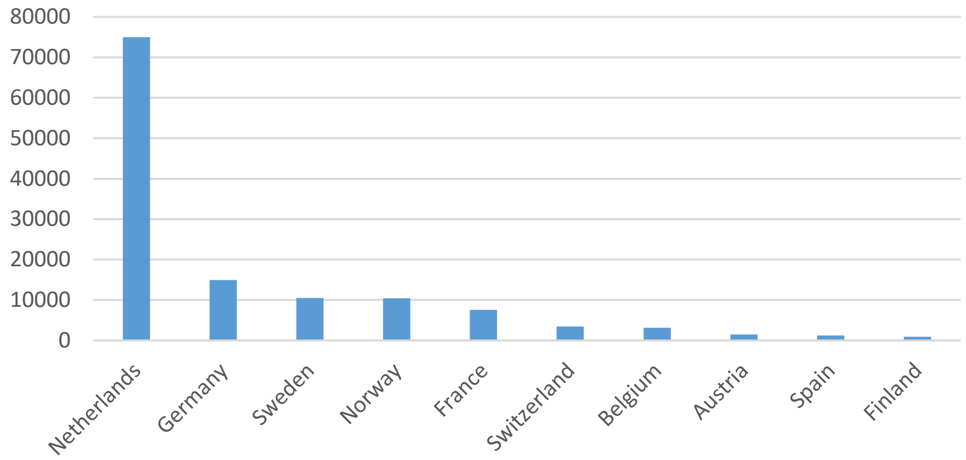


Figure 42: Cumulative PHEV sales between 2006 and the end of 2015, TOP 10 countries in EU28 [number of vehicles] (Irle 2016).

3.3.3 Engine Cylinder Size Distribution

The engine cylinder size of combustion vehicles POM shows no statistically significant trend. This means that engines are not getting larger, however, according to the ICCT (2016), the average number of cylinders has decreased from 4.1 in 2000 to 3.9 in 2015. The average traction power of vehicles POM has however been steadily rising, indicating that the same size engines are producing more and more power, see Figure 43. This has been accomplished while increasing fuel economy and reducing NOx and hydrocarbon emissions, suggesting that advanced combustion technologies, catalytic converters, and other systems such as computer tuning and start-stop systems are responsible rather than raising combustion temperatures or compression levels. The contribution of the increase in hybrid-electric drivetrains, with relatively smaller combustion engines, is limited due to their low sales.

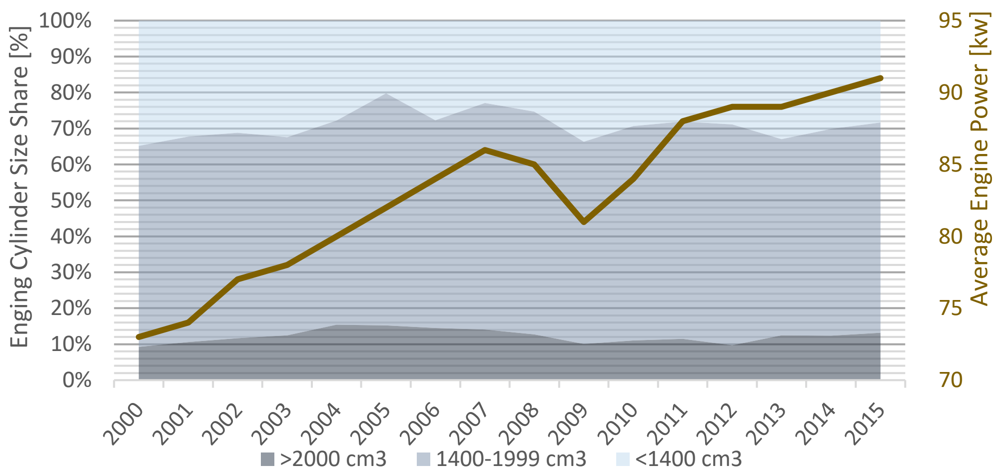


Figure 43: Engine cylinder size distribution for POM vehicles in EU28 [%] (Eurostat, ICCT 2016).
NB cylinder size refers to internal combustion engines. Thus, HEVs and PHEVs are included, but not BEVs.

3.3.4 Age of Vehicle Stock and End- of-Life Vehicles

The age of the vehicle fleet is highly relevant for estimating scrapping rates and for estimating the component and CRM content of both the fleet and ELVs. Eurostat only reports the age categories of the vehicle stock in Europe, bucketed into 0-2 years, 2-5 years, 5-10 years and 10+ years. The proportion of vehicles in the 10+ year category has risen, mostly at the expense of the 0-2 year category which would suggest the overall age of the stock increasing. According to the

ProSUM stock-flow model, the average age of vehicles in service in the EU rose from 7.9 years in 2000 to 9.6 years in 2015, see Figure 44. The rise in average vehicle age can mostly be explained by a steep dip in POM vehicles and lower overall scrapping rates following the 2007/8 economic crisis. With less input and less scrapping, more cars reached older age, explaining the rise of the percentage of vehicles older than 10 years. Again, variance suggests that it is too early to tell if the trend has reversed, but if the current rate of vehicle sales and vehicle scrapping persists, the average age will not continue to rise further.

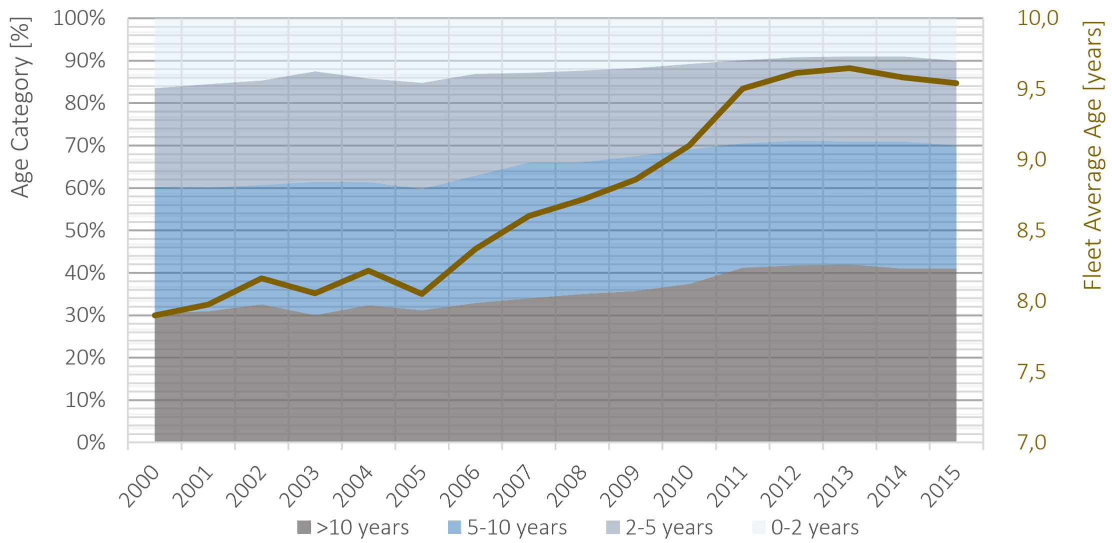


Figure 44: Fleet age categories' distribution [%] (Eurostat) and fleet average age [years] in EU28 (ProSUM model (Huisman et al 2017)).

The picture for the average and median age of ELVs in the EU is more uncertain but may play an additional role in the rise of the average stock age. Data that unequivocally shows the vintage of recycled ELVs in a given country and year, thus enabling calculation of the average and median scrapping age, is comparatively scarce. Additionally, mandated ELV data collection only began in 2009. The data that exist are shown in Figure 45, alongside a calculation based on the data from the ÖKO-Institut (Melhart 2011) and the estimation from the ProSUM model (Huisman et al 2017), which is based on similar methodology.

The median age at scrapping, EU wide, is estimated to be approximately 14±1 years by the ProSUM model, with the ÖKO-Institut's data showing a dip in 2007. One would expect the average age to typically be above the median because very old cars would add weight to the above-median vehicle counts. An inversion, e.g. the average below the median is shown in Swedish data for 2008 and 2009, and also in the German data for 2009. This would mean an unusually high number of young vehicles being scrapped. Both years featured scrapping premiums, possibly incentivizing such a shift. It would also correlate well with the rise in average age shown in Figure 45.

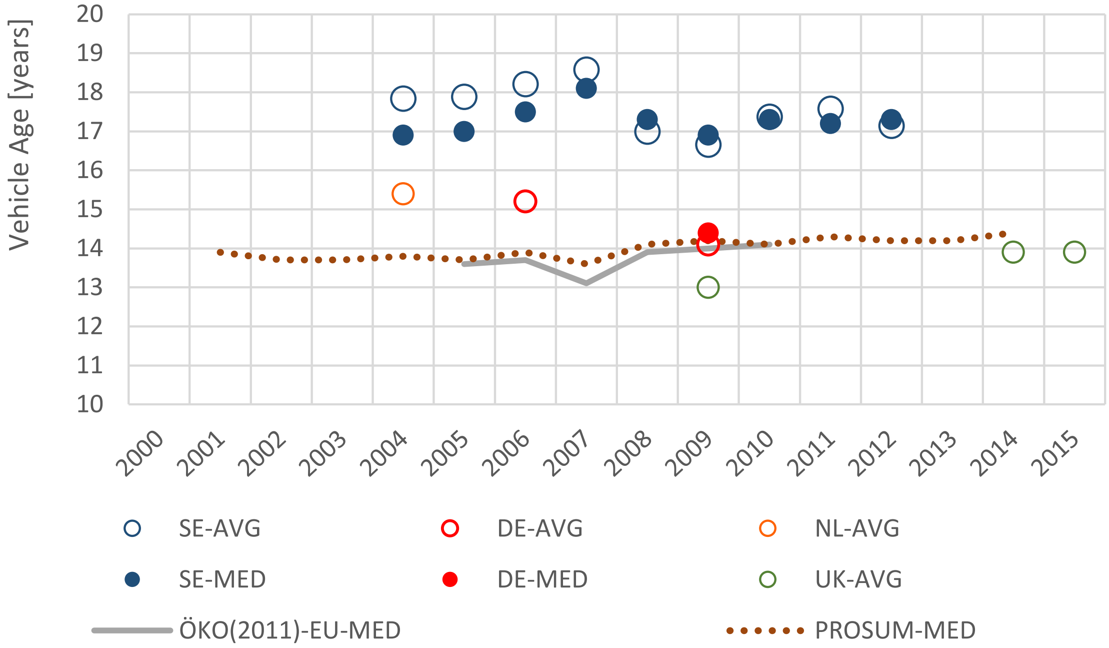


Figure 45: Vehicle age at end-of-life in EU28, average and median [years] from data and models (BilSweden, 2015; Kohlmeyer 2011; SMMT 2016; Melhart 2011; ProSUM model (Huisman et al 2017)).

3.4 Vehicle trends

3.4.1 Steel, aluminium and magnesium alloys

Steel is the main material used for structural parts of vehicles, due to its high strength and ductility, ease of forming as well as relatively low cost. A large share of automotive steel is mild steel with a relatively low strength-to-weight ratio (Abraham and Ducker Worldwide, 2015). In the past decades, however, mild steel has been increasingly displaced by various types of conventional high-strength steel (HSS), advanced high-strength steel (AHSS), aluminium alloys, magnesium alloys and polymer materials. Among the drivers behind this trend are increasing safety demands (i.e. better crash resistance), light-weighting and manufacturing cost reductions.

Despite the shift to lighter materials, average vehicle mass has been increasing, as shown in Figure 46. There are two reasons for this. Firstly, the sales of sport utility vehicles (SUVs) have increased at the expense of lighter vehicle types (International Council on Clean Transportation, 2016). Secondly, the weight gains obtained by material substitution have been more than compensated for by additional equipment for safety, comfort and entertainment. In fact, all vehicle segments except SUVs, have increased in average mass by around ten percent over the last 15 years (International Council on Clean Transportation, 2016).

It can be expected that light-weighting by material substitution will continue at high pace in the coming years in an effort to reduce fuel consumption and thereby CO_2 emissions. The market analyst Ducker Worldwide conducts studies on the historical and project future content of steel and aluminium in automobiles based on manufacturer surveys for a the most common vehicle models (in studies of the European market, these models account for about two thirds of the sales of new cars). Figure 46**Error! Reference source not found.** shows their estimated historical and projected future content of AHSS and ultra-high-strength steel (UHSS) in North American light vehicles (data for Europe were not available).

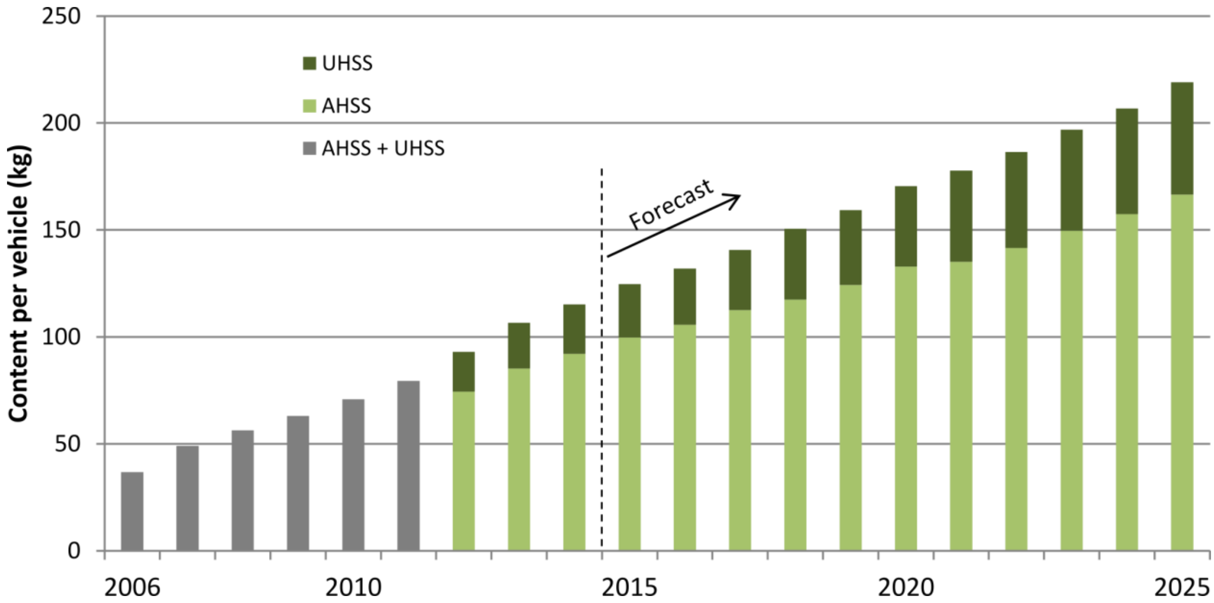


Figure 46: Average advanced high strength steel (AHSS) and ultra-high strength steel (UHSS) content in North American light vehicles, historic and forecast.
Note that North American light vehicles are about 25% heavier than the average European passenger vehicle. Adapted from (Abraham and Ducker Worldwide 2015)

Although neither iron nor aluminium is considered critical for the EU, the choice of light-weighting material may have an impact on CRM use in vehicles, due to the various alloying elements used. Chromium and niobium are considered critical and commonly used as alloying elements in steel. The majority of chromium is use in stainless steels, which require a minimum of 10.5% chromium by mass (European Commission 2014). It is also used for strengthening but at lower mass fractions (Daigo et al. 2010). Although chromium is sometimes used in AHSS, it is difficult to know whether the light-weighting trend will lead to an increased use of chromium. Niobium is used for grain refining, transformation control and precipitation hardening, typically at 0.02-0.05% of the mass (Mohrbacher 2006, Mohrbacher 2010). Niobium is used in many different steel grades, including most of HSS and AHSS grades as well as certain types of low-strength steel, but statistical information about the share of niobium-containing alloys is not available. Since mild steel does not contain niobium, it is expected that an increasing use of HSS/AHSS will lead to increasing niobium content in vehicles. It is not possible to provide any quantitative estimate, in particular, because it is not known which steel types are displaced by HSS/AHSS.

Molybdenum is used in some HSS and AHSS, and its use in vehicles is therefore increasing as these materials become more common. Molybdenum is however currently not considered critical for the EU (European Commission 2014). In contrast to aluminium alloys, the mechanical properties of steel are controlled by the processing route, e.g. cooling time, than by alloying additions. Hence, HSS and AHSS do not necessarily have a very different chemical composition compared to low and medium strength steels. The switch to HSS and AHSS may therefore have a relatively low impact on the composition of vehicles, although some increase in Nb and Mo could be expected. Ironically, the most visible effect may be an overall reduction of steel in vehicles in vehicles, as low strength steel parts are replaced by lighter high-strength steel parts.

One of the single most important shifts in material use for modern vehicles has been the switch from cast iron to cast aluminium engine blocks. The development started for petrol vehicles in the 1970s but remained limited for diesel vehicles until the mid-1990s for technical reasons

(European Aluminium Association 2015). Aluminium passed cast iron in 2005 as the most common material for engine blocks in European cars, and has continued to increase its share since then (European Aluminium Association 2015).

Engine blocks and other engine components, e.g. cylinder heads, air intake manifolds, various pumps, housings and covers, are important from a recycling perspective both due to CRM content and the role the play in the aluminium recycling cascade. The cast alloys used in these components play the role of a bottom reservoir in the aluminium recycling cascade due to their high content of alloying elements (Si, Cu, Zn, Mg) and high tolerance for impurities such as Fe (Løvik et al. 2014). Mixed aluminium scrap, such as that obtained from ELV shredders, cannot be used to produce higher purity alloys and therefore ends up in engine blocks and components from similar alloys. The proper functioning of the aluminium recycling system therefore depends on this channel to absorb the lowest quality scrap. In electrified drivetrains engine blocks and other cast aluminium components are displaced, which could have serious consequences for the possibility to recycle this aluminium. Cast aluminium is normally alloyed with silicon at 8-20% of the mass, and is thereby the single most important application of silicon metal, which is considered critical to the EU (European Commission 2014). Figure 47 shows the increasing content of aluminium alloys (cast and wrought) in European light vehicles.

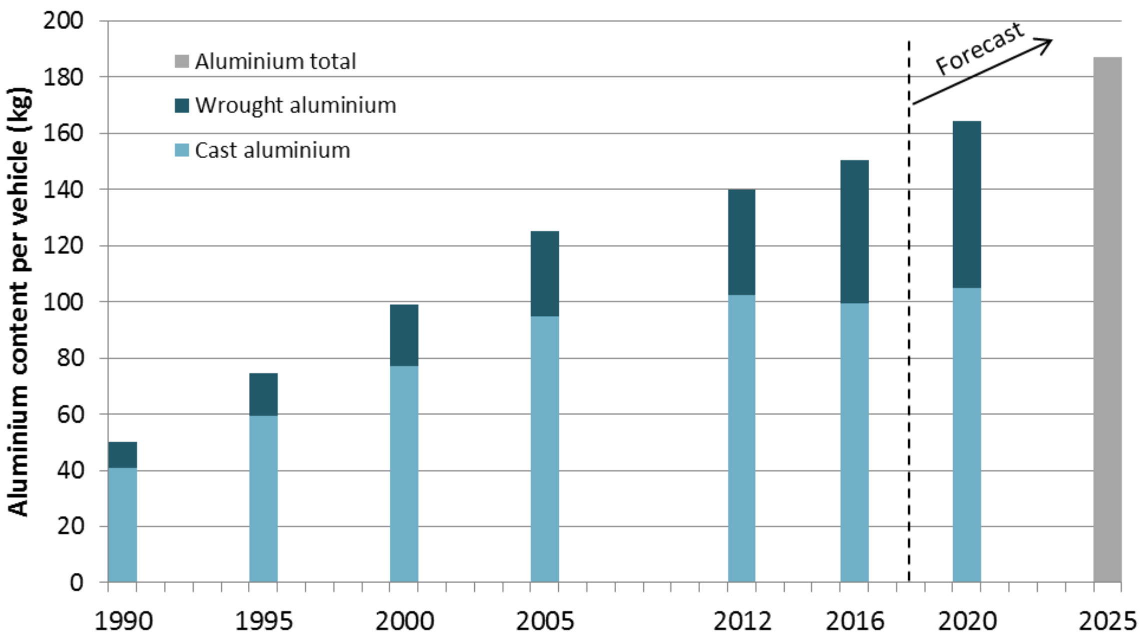


Figure 47: Cast and wrought aluminium content in European light vehicles, historic and forecast. Adapted from (Ducker Worldwide 2016)

In current ELV recycling, however, the recycling rate of cast alloys is high, and since silicon is preserved as an alloying element in the recycling process, it is one of the few CRMs in vehicles that has a high end-of-life recycling rate. Cast aluminium use has increased in the past decades, but growth has slowed down and, therefore, the coming change in the ELV flow will be less significant than for AHSS.

Wrought aluminium use, on the other hand, is still growing fast and expected to continue to do so, mainly due to increasing penetration in structural body component and closures (Figure 48 and 49). However, the effect on CRM use will be limited, as these alloys employ much smaller amounts of silicon. Some wrought alloys (5xxx-series) contain magnesium up to around 5% and are being used in sheet applications with high growth potential such as doors (European Aluminium Association 2015). This might give a small contribution to the overall increase in the use of magnesium (also considered critical). In the current recycling processes, magnesium present in mixed aluminium scrap is not functionally recycled due to its negative influence on aluminium cast alloys, and is often removed in a so-called de-magging process. In the worst case, increasing use of magnesium in aluminium alloys could lead to an increased need for this additional step, which in turn could mean a slightly reduced recovery of aluminium.

Manganese is used in many cast and wrought aluminium alloys at a mass fraction up to around 1% (The Aluminum Association 2009). Since aluminium usually replaces steel alloys that typically contain around 1% manganese, it can be expected that increasing aluminium use leads to slightly less manganese in vehicles. Aluminium alloy standards are usually defined by their lower and upper limits for Si, Mg, Mn, Fe, Cu, Cr, Zn, and Ti. Other elements, such as rare earths, may be added as long as they remain below the specified general limit for “other elements”. Most available information for aluminium alloys in vehicles refers to the standard alloy specifications and can therefore not be used to deduce the content of more exotic alloying elements.

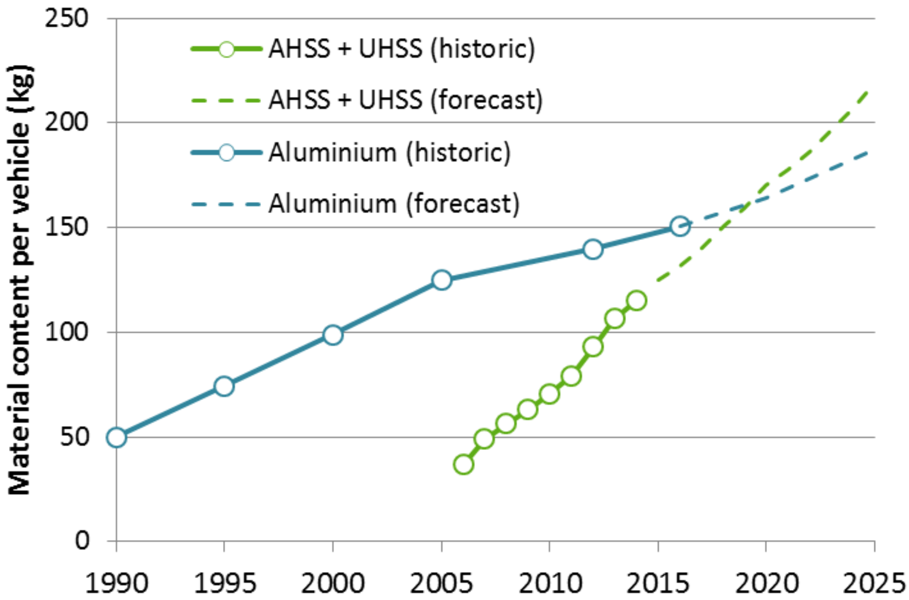


Figure 48: Average aluminium content in European vehicles placed on the market, and average advanced high strength steel content in North American vehicles placed on the market.

The increasing use of cast magnesium alloys for complex light-weight shapes such as steering wheels, seat frames, instrument panel beams and gear boxes could have a larger effect on the use of magnesium in vehicles than magnesium as alloying element in aluminium. Quantitative information on the increase in magnesium alloys use is scarce, but it appears to be have been rather limited so far and to be expected to continue being so. This is indicated by the Volvo Cars case, where the use of magnesium alloys increased by only 7 kg in a full passenger car between the model years of 2007 and 2015 (Hamza and Trinh 2017), while aluminium alloys simultaneously increased by around 80 kg. Market projections indicate that the increase of magnesium is expected to continue to be much smaller than that of aluminium: magnesium is projected to increase by slightly less than 30% and aluminium to more than double between 2010 and 2030 (Statista 2017).

3.4.2 Catalytic converter

The catalytic converter is an important source of secondary raw materials due to its content of the platinum group metals platinum, palladium and rhodium, which are also considered critical for the EU (European Commission 2014). The purpose of the catalytic converter is emissions control, and its deployment has therefore closely followed the development of emissions regulations in Europe, as illustrated in Figure 49.

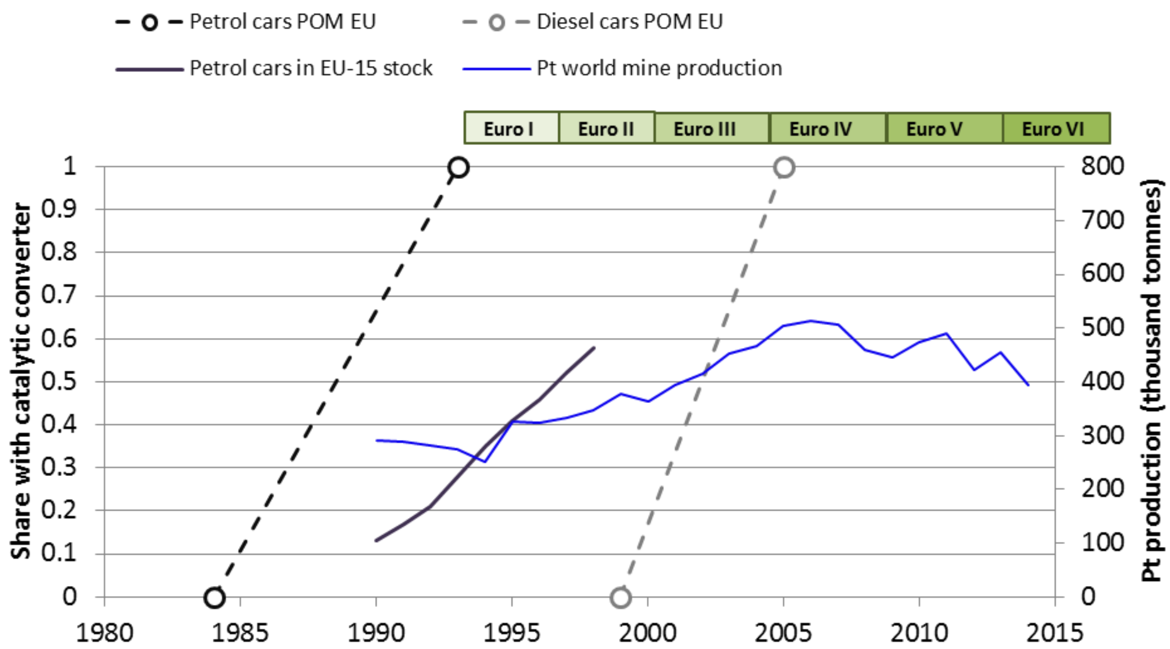


Figure 49: Introduction of European emissions regulations and deployment of catalytic converters in petrol and diesel passenger vehicles (estimated).
Also shown are the share of petrol cars in the vehicle stock with catalytic converter (black solid line) and the world primary production of platinum (blue line).

The first European vehicle models with catalytic converter appeared in 1985 (Hagelüken et al. 2006), and with the introduction of the Euro I regulation in 1993, petrol vehicles were required to have one to meet emissions limits (European Environment Agency 2001). From the adoption of the Euro IV regulation in 2005, diesel vehicles have also been required to have a catalytic converter to meet emissions limits for NOx (Molotova et al. 2013). Consequently, all European internal combustion engine vehicles (ICEVs) produced after 2005 are equipped with catalytic converters. The technical requirements differ between petrol (gasoline) and diesel vehicles: catalytic converters for petrol vehicles can be produced with a mixture of palladium/platinum and rhodium, with more palladium than platinum, while catalytic converters for diesel vehicles contain mainly platinum and some palladium (Johnson Matthey 2013).

Due to the high cost of the raw materials, technological development is aimed at material substitution and reduced use of PGMs. At the same time, the progressively stricter emission limits drive a need for improved performance catalytic converters, which could potentially lead to higher material requirements. Quantitative data on the actual change of PGM content with time is not available. Catalytic converters also contain REEs such as lanthanum and cerium (Andersson et al 2016) but quantitative data on content and its change over time is scarce.

3.4.3 Electrical and Electronic System

One of the key trends in the vehicle configuration in the past two decades has been the increasing electrification and automation of vehicle functions. New devices are embedded in control systems which either fulfil a task previously performed by the driver (e.g. power windows instead of manual adjustment), or add entirely new functions to the car (e.g. video entertainment systems). The drivers behind these developments are increasing safety requirements, comfort, performance and entertainment. New functions are typically first employed in more expensive, higher segment cars, and if successful move on to become standard equipment in all vehicles or even required by safety or emissions regulation. In general, the trend has been an increasing number of electrical and electronic devices, which to varying degrees rely on the use of valuable and/or critical raw materials. Figure 50 shows some of the new functions/systems and their level of adoption in automobiles.

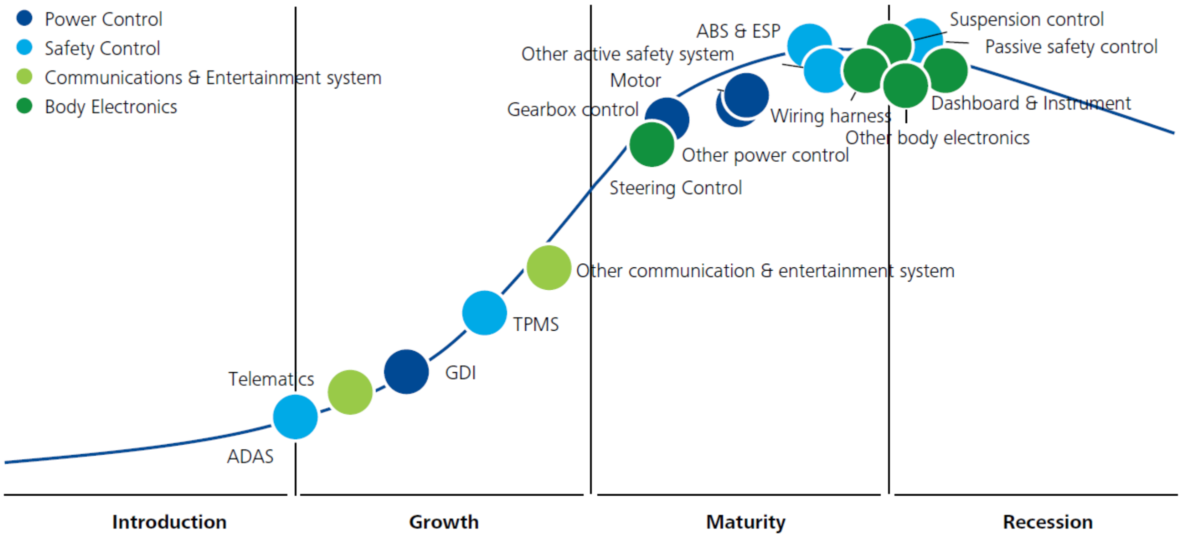


Figure 50: Market penetration of various electronic systems in vehicles (Deloitte China Automotive Practice 2013). ADAS = advanced driver assistance systems, GDI = gasoline direct injection, TPMS = tire pressure monitoring system, ABS = anti-lock braking system, ESP = electronic stability program.

As can be seen from Figure 51, the on-board computer and air conditioning are among the devices and systems that penetrated the market in the past two decades and will therefore increasingly appear in ELVs in coming years. Another example of the trend is the number of electronic control units which increased from 16 to 60 between the 1997 and 2012 VW Golf versions (Kohlmeyer et al. 2015). The observation that the same size engines have become more powerful (see Figure 43), also suggest an increase in systems such as computer tuning and start-stop systems.

In the last few years, however, increasing integration of electronic control systems may have reversed the trend and actually led to a slight drop in the amount of devices embedded in vehicles (Restrepo et al. 2017). An example here is the vehicle dynamics control, where the antilock braking system (ABS), electronic stability program (ESP) and traction control system (TCS) have been integrated or replaced one another (Restrepo et al. 2017).

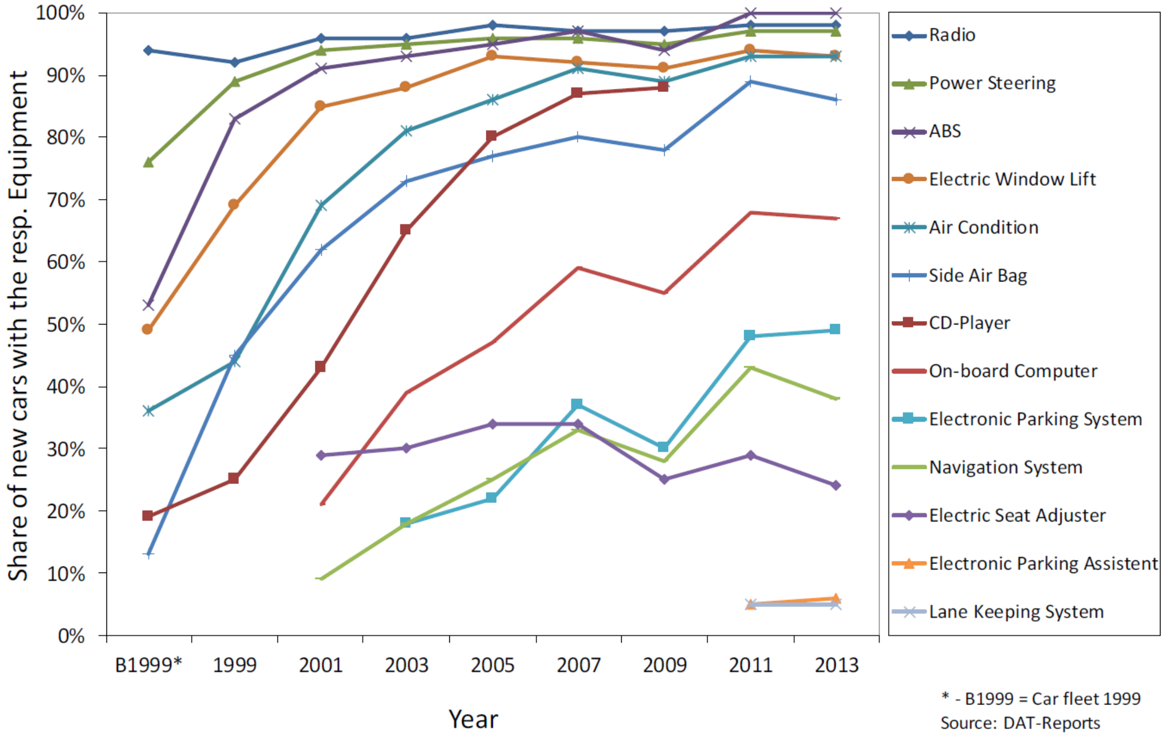


Figure 51: Market penetration of electronic devices in new cars sold in Germany (Sander 2014).

Data on CRMs used in vehicle electronics are scarce and information about temporal changes is virtually non-existent. Nevertheless, some recent estimates have been made based on the observed penetration at the device level, which can give some indication of the change happening. Figure 52 shows that the estimated content of Nd, Dy, Co, Au and Pd in the electrical and electronic system of passenger vehicles has increased significantly over time. The absolute values are estimated based on four studies (Alonso et al. 2012, Cullbrand and Magnusson 2012, Widmer et al. 2015, Restrepo et al. 2017), while the relative change over time is from a Swiss study, with cars from 1998, 2007 and 2014 corresponding to the average ELV, average vehicle in stock and average new vehicle POM in Switzerland respectively (Restrepo et al. 2017).

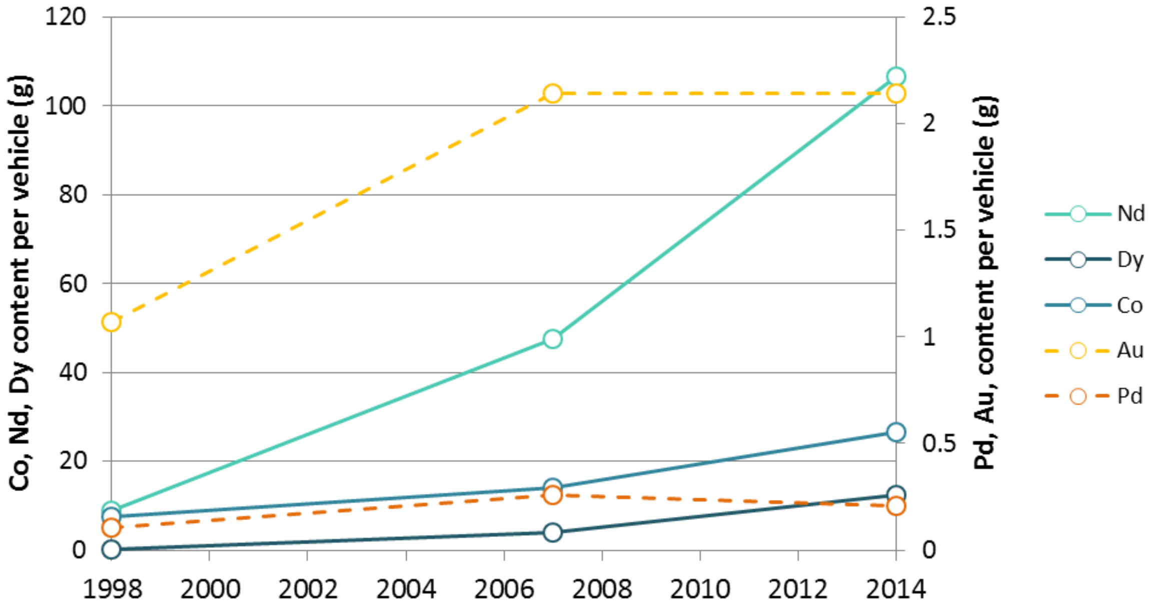


Figure 52: Estimated content of selected critical and valuable elements in electrical and electronic system of passenger vehicles over time.

3.4.4 Electrified Drivetrains

As illustrated in previous sections and Figures 40-46, three electrified drivetrain configurations are currently the most commonly used: HEV (hybrid electric vehicle); PHEV (plug-in hybrid electric vehicle); and BEV (battery electric vehicle). Other examples that are not (yet) common on the market are continuous power supply electric vehicles (to be used on electrified road systems) and fuel cell vehicles.

Both HEV and PHEV hold an internal combustion engine, an electric motor and a traction battery. The BEV runs only on electricity via on-board batteries that are charged from the electricity grid and does not hold an engine. There are many alternative components and configurations for these electric drive systems and none that is optimal for all vehicle applications and vehicle segments (Lundmark et al. 2014). This is reflected in the span of different drive systems and battery solutions currently on the market. Consequently, absolute as well as relative material and elemental compositions vary between electrified vehicles. However, the following components are usually included in an electrified drivetrain (Lundmark et al 2014):

1. Traction battery pack (including a battery management system);
2. Battery charger (often on board);
3. Electric machine (used as a traction motor and sometimes as a generator);
4. Propulsion power converters (e.g. DC/DC and DC/AC converters);
5. DC/DC converter (with low voltage output for auxiliary equipment such as windshield wipers, radio and lights), replacing the alternator in a conventional car;
6. Safety equipment (to break high currents and to monitor the battery);
7. High voltage cables; and
8. Electric cooling compressor (to keep the batteries from overheating).

All the components listed may contain elements targeted in ProSUM. Traction batteries are further presented in Section **Error! Reference source not found.**. High voltage cables commonly use copper or aluminium as conductive material (total mass of around 10 kg for HEVs and less for BEVs (Lundmark et al. 2014)). The other components typically contain electronics and associated CRMs. In addition, some, but not all, types of electric machines contain permanent magnets (permanent magnet synchronous motors and permanent magnet assisted synchronous reluctance machines). Data for the CRM content of parts of two of the listed electric drivetrain components are mapped in ProSUM: traction battery cells and electric machine permanent magnets (Løvik et al. 2017). Trends in material composition have not been possible to account for.

3.5 Future Trends of CRM in ELV flows

Based on observed historic and current trends for fleets and vehicle designs, this section qualitatively discusses CRMs in generated ELV flows at present as well as that of the near future, when vehicles put on the market today will on average reach end-of-life. Also, some observations are made regarding ELV flows which will be generated later in the future, based on current discussions about the future development of the vehicle fleet and car designs. Quantified estimates of the total mass of CRMs in vehicle stock and flows are not provided in this report. These will be generated as part of coming work in ProSUM.

3.5.1 Total Mass of Vehicle Stock and End-of-Life Vehicles

Overall, it can be expected that the total mass of the vehicle stock and annually generated ELVs will increase slightly over the coming years. This is due to the observed increase in the number of vehicles in the stock and their average mass. The median age at ELV is estimated to around 14 years for the last 15 years, implying that the median vehicle recycled today was manufactured in 2003, and, conversely, that we can expect half of all vehicles manufactured in 2017 to reach end of life by 2031.

3.5.2 Drivetrain Types in ELV Flows

The diesel boom in the 2000s will lead to a higher share of diesels in generated ELVs in the coming years. In the longer term, however, diesels may come to constitute a smaller share of ELVs if, as currently expected, their market share decreases due to increasing problems with particulate matter emissions in European cities.

Electrified vehicles will only constitute a small minority of ELVs for a long time. They started to come into the market around ten years ago, and even if sales now increase rapidly, they currently only represent around 3%. HEV still dominate the sales, while PHEV and BEV took off a few years ago. Since sales are concentrated to a few countries, such as Germany, Norway, France and the Netherlands, it may be expected that EVs in ELV flows will be fairly concentrated to certain countries too.

The distribution of different EV drivetrains affects the quantity of CRMs in the ELV flow. PHEVs with Li-ion battery typically require significantly less lithium, copper and REE, but more cast aluminium (combustion engine) and PGMs (catalytic converter) than a BEV with Li-ion battery.

3.5.3 CRMs in Structural Metals in ELV Flows

It is clear that the share of steel in cars has been decreasing and substituted by aluminium, magnesium and plastics. Furthermore, steel types have shifted towards more high-strength and advanced high-strength steel.

In terms of CRM quantities in the ELV flow, the shift of steel types may have had a relatively small impact, although some increase in niobium and molybdenum is likely.

Only a small increase in cast aluminium content is expected in the coming years, as its use in new vehicles has only grown slowly in the past decade.

With the rapid increase of wrought aluminium use, magnesium as an alloying element also increases. Other CRM alloying elements are likely also involved but such information is largely lacking. In the coming years, the amount of wrought aluminium in ELVs will increase substantially but cast alloys will retain the largest share of the aluminium scrap. Magnesium alloys have also increased their share in vehicles over the last ten years but less than aluminium. If trends continue as predicted, magnesium as an alloy and as an alloying element in aluminium, will further increase in ELV flows in the longer term.

3.5.4 CRMs in Catalytic Converters in ELV Flows

The late introduction of catalytic converters for diesel cars combined with the European diesel boom in the 2000's will lead to a large increase in platinum available from ELVs in coming years. In the longer term, however, it is currently expected that diesels will decrease. Also, any electrified drivetrain will reduce the need for catalytic converters and related content of PGMs and REEs. Furthermore, there are continued efforts to substitute PGMs in catalytic converters due to their high cost. In sum, it may be expected that at least over the 15 coming years, the availability of PGMs and REEs in catalytic converters will increase in ELV flows. It could be expected that the availability eventually will peak and then stabilize or decline. This will depend on the future balance between stricter emission targets and the substitution of PGMs in catalytic converter material, phase out of diesel engines, and introduction of electrified vehicles.

3.5.5 CRMs in Electrical and Electronic Systems in ELV Flows

It is clear that EEE has increased significantly in vehicles over the last years and can fairly soon be readily observed in flows of ELV. As an example, a rough estimate based on these numbers would indicate that the amount of gold and neodymium per ELV could increase by 2 and 10 times respectively in the next 10-20 years (Restrepo et al. 2017). In the longer term, the level of EEE and associated CRMs in ELV flows are likely to be higher than today but there are indications that integration of components may reduce or even slightly reverse the increase. However, an increase in electrified drivetrains will involve substantial increases in EEE. In line with the reasons above, this will constitute a small share of ELV flows, possibly concentrated to a few countries, for a long time.

4 Batteries

This chapter presents the product trends for batteries which have three dimensions:

- Changes in the demand for batteries dues to changes in the battery-containing products, which are mainly EEE, electric vehicles and energy storage systems;
- Technological changes of the electrochemical systems used to power a product or store energy and their characteristics (battery weight, composition, lifespan etc.); and
- The resulting changes in the consumption of raw materials.

4.1 Product Trends BATT

4.1.1 Factors for Changes in the Battery Market

The battery market is dependent on the market for products which contain the batteries. Changes at the product function level, i.e. market changes due to new developments and usages of products, are the main drivers for changes to the battery markets and, therefore, changes to the average CRM content of the batteries. Battery markets are at different stages on the S curve. While the diffusion of batteries for electric mobility is increasing very rapidly, other markets like batteries for portable EEE are slowly increasing or stagnating.

In general, the main factors for changes in the average use of CRM in batteries are not changes to the composition of batteries within a specific electrochemical system but market shifts from one electrochemical system to another. The following factors may have a significant influence on changes in CRM parameters:

- Technical requirements related to the function of the product in which the battery is used:
    - Battery specific energy;
    - Charge/Discharge rate capability;
    - Lifetime and calendar life; and
    - Battery volumetric energy.
- Economic requirement related to battery price. This is particularly true for batteries containing Co, where price can represent a significant part of the battery cost.
- Legislative requirements e.g. Article 4 of the Batteries Directive 2006/66/EC prohibits the placing on the market of portable batteries or accumulators that contain more than:
    - 0.0005 % of mercury by weight;
    - 0.002 % of cadmium by weight including since January 1st 2017 for batteries used in cordless portable tools.

4.1.2 Trends in Smaller, Lighter, More Powerful Batteries

In general, there is a trend to more energy-efficient devices, which means either that the battery weight remains stable and the devices offer more functions, or the weight of the battery decreases, e.g. shift from an AA to an AAA battery, or to button cells, or use of lighter batteries, for the same product functionality. Also, the miniaturization trend presented in Section **Error! Reference source not found.** affects the battery volume and weight.

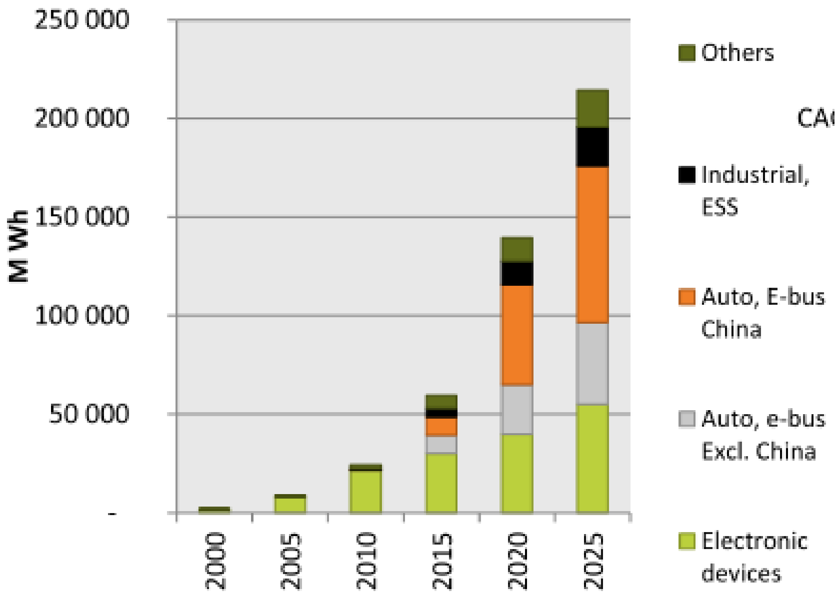
The changes can be very abrupt. A product-centric example of a rapid change of the technical requirements is the shift of the laptop towards thin and “ultraportable” notebooks, in which the traditional battery shape used since the 1990s (based on a standard cylindrical shape Li-ion cell having a diameter of 18 mm) could not be used anymore. The new battery designs require a maximum thickness of 10 mm or less and, therefore, the usage of a new battery technology with new material composition.

4.1.3 Divergence and Convergence

The trends described for EEE in Section **Error! Reference source not found.** are reflected in the battery markets. The trend towards ‘smarter’ hardware where products (including vehicles) are increasingly embedded with electronics, fitted with sensors, communication, data modules and other technologies results in the diffusion of batteries in new types of smart products (Section **Error! Reference source not found.**). The consequence that products containing electronics and batteries will be ever more diffuse also affects the dissipation of the CRM contained in batteries. The convergence/combination of products observed in recent years has also causes a recession in some battery types e.g. for markets of battery-containing products like digital cameras and MP3-players.

4.2 Data Availability and Estimation Approach

Avicenne (2016) estimates that whereas electronic devices accounted for 50% of the sales of lithium-ion batteries in 2015, the largest application is expected to be electric mobility in 2025 with a share of 56% (Figure 53). This is in line with the estimates of Thielmann et al. (2012), who expect that, depending on the scenario and its underlying framework conditions, between 50% and more than 70% of lithium-ion batteries are expected to be used in electric mobility applications in the next 10 years, alongside stationary applications and mobile or portable electronic products.



Others: medical devices, power tools, gardening tools, e-bikes...

Source: AVICENNE Energy 2016

Figure 53: Lithium-ion battery sales forecast in MWh, worldwide (Avicenne, 2016)

Based on this analysis and available put on the market data (WP3), three battery applications were identified as future trends:

1. Electric mobility, including vehicles, e-bikes, e-scooters etc;
2. Portable electric and electronic equipment; and

3. Energy storage

Applications such as military, wearables and IoT are early adopter markets that may become key in the future (Laslau et al. 2015). However, insufficient data is available to fully describe the trends for batteries at present.

4.2.1 Electric Mobility

According to the E-mobility Battery R&D Roadmap 2030 produced by Eurobat (2015), three existing battery technologies are expected to have the greatest potential for further technological improvements over the next decade:

- Advanced lead-based batteries – for start-stop vehicles and micro-hybrid vehicles;
- Lithium-ion batteries – for electric vehicles and all types of hybrid vehicles; and
- Sodium nickel chloride batteries – for heavy duty electric vehicles and plug-in hybrid vehicles.

Avicenne (2016) expects an increase of the market shares of advanced lead-acid and lithium-ion batteries between 2010 and 2020, related with an increase of the sales volumes of PHEV and full HEV (Figure 54). Advanced lead-acid batteries are smaller, lighter batteries and offer an approximate 20% lead weight reduction (Eurobat, 2015). For example, valve-regulated lead acid (VRLA) batteries containing enhanced levels of carbon in the negative plate belong to the advanced lead-based batteries. In the European market, lead-based batteries are not considered as promising for traction purposes (Thielmann et al., 2012b). Sodium nickel chloride batteries have been commercialized since the 1990s and originally found application in electric vehicles and hybrid electric vehicles, mostly buses, trucks and vans (Eurobat, 2015; Restello et al., 2011).

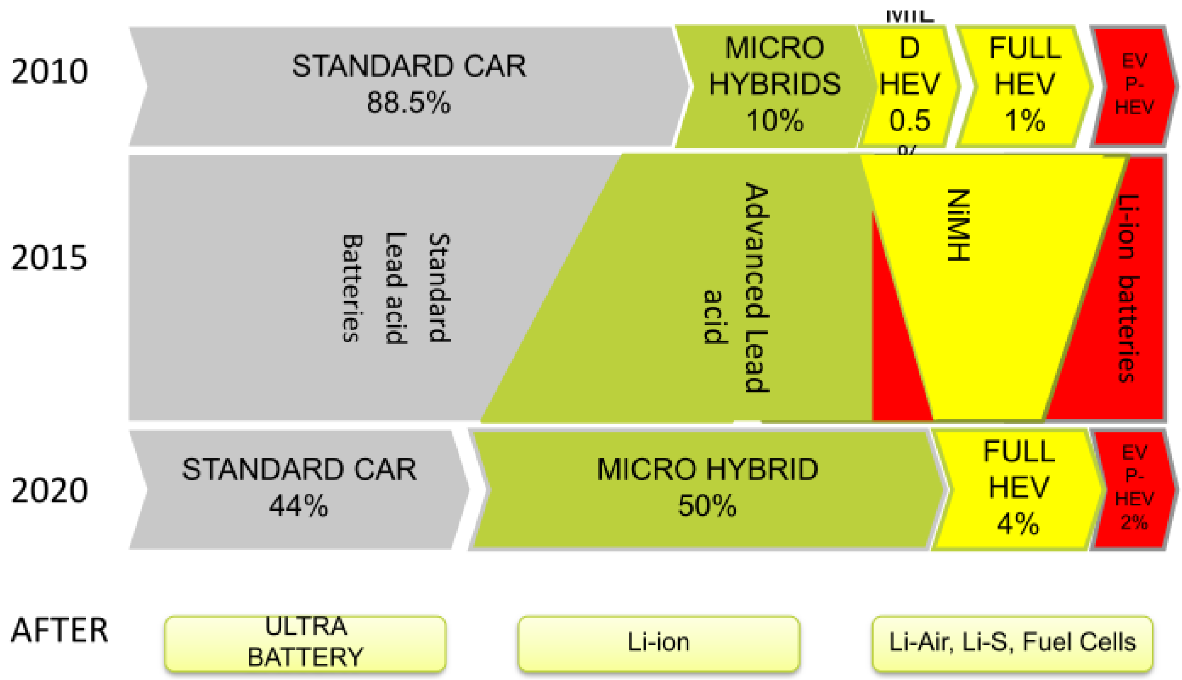


Figure 54: Trends in the use of batteries in vehicles (Avicenne, 2016)

Current research activities aim at developing new or alternative technologies like lithium-air, lithium sulphur, lithium-polymer and solid-state lithium. A significant advancement in one or more of these chemistries could prove disruptive to the industry; however, the extensive testing needed to bring a new chemistry into a production vehicle makes it unlikely this would occur before 2020 or 2025, as there are no game-changing technologies approaching the consumer market (Navigant Research, 2015; Thielmann et al., 2012b; Blagoeva et al., 2016; Anderman, 2015; Avicenne, 2016; Ahlberg Tidblad, 2015).

Laslau et al. (2015) forecast lithium-sulphur and solid-state batteries to reach 4% and 2% market penetration in 2030 in transportation, respectively, rising to 8% and 12% in 2035 (Figure 55). Until 2020, Li-ion will dominate, evolving to become advanced Li-ion, defined by Laslau et al. (2015) as a varied mix of higher-voltage and higher-capacity materials, a step beyond today's NMC or NCA paired with graphite.

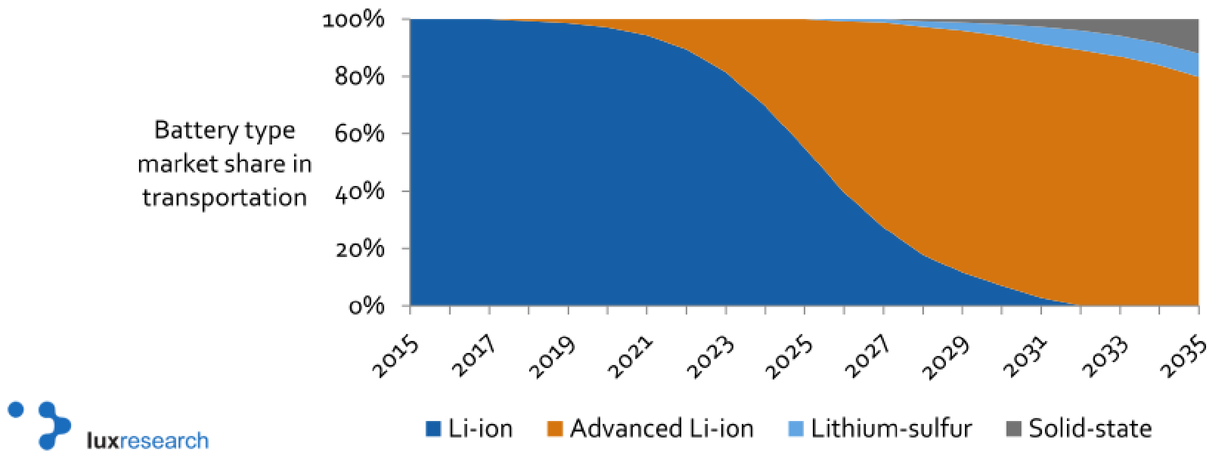


Figure 55: Battery type market shares in transportation between 2015 and 2035 (Laslau et al., 2015)

The literature clearly states that li-ion technologies have the most competitive position in electric mobility and that this is not expected to change before 2025, therefore, data collection was prioritised on lithium-ion batteries.

Focus on lithium-ion batteries

According to a commercial report produced by Navigant Research (2015) providing confidential global market forecasts until 2024, the global market for Li-ion batteries in light duty and medium/heavy duty vehicles is expected to grow from $7.8 billion in 2015 to $30.6 billion in 2024. This development is pushed by national and European policies, including the setting of EV deployment targets by the Electric Vehicles Initiative (EVI) for 2020, the Paris Declaration on Electro-Mobility and Climate Change and Call to Action for 2030, and the IEA 2DS.

Thielmann et al. (2012) dated the mass production of HEVs and small industrial trucks using lithium-ion batteries to approximatively 2015. They forecast the mass production of the following products equipped with lithium-ion batteries for:

- Between 2015 and 2020 for PHEV and BEV, scooters, hybrid forklift and 3.5 t vans;
- Approximatively 2020 for starter batteries and hybrid tractors; and
- After 2020 for electric forklifts, electric buses and hybrid trains.

An overview of the current and future uses of lithium-ion batteries for electric mobility is provided by Thielmann et al. (2015a) from Fraunhofer ISI. Table 9 shows the market forecast and development for electric mobility.

Table 9: Global market for lithium-ion batteries

Application for electric mobility	2015		2020	2030	>2030
	Current LIB technology	Market size	Market size	Market size	Diffusion trend
Two-wheelers (ebikes, scooter, pedelecs, motorbikes etc.)	NMC	~5 Mio, ~10 GWh	~10 Mio, ~ kWh, >10 GWh	~x*10 Mio, ~ kWh, ~x*10 GWh	Diffusion
HEV	LFP, NCA, NMC	~1,5 Mio, ~1 kWh, 1-1,5 GWh (NiMH + LIB)	~1 Mio, je ~1 kWh, ~1 GWh (NiMH + LIB)	<1 Mio, je ~1 kWh, <GWh LIB Market	~100 % LIB HEV disappear
PHEV	NMC, NCA, LFP	~200-250 Tsd., ~10 kWh, 2-3 GWh	~0,5-1,5 Mio, je ~10 kWh, 5-15 GWh	~1,5 Mio, je ~10 kWh, <100 GWh	Saturation, decline
BEV	NMC, NCA, LFP	~200-250 Tsd., ~25 kWh, 5-7 GWh	~0,5-1,5 Mio, 25-40 kWh, 20-60 GWh	~5-10 Mio, 25-60 kWh, 0,1-1 TWh	Diffusion (global change)
Utility vehicles (light vehicles, trucks, busses)	LFP, NMC, NCA	~x Tsd., ~50-250 kWh,~ GWh	~x*10 Tsd., ~50-250 kWh, ~x GWh	~1 Mio?, ~50-250 kWh, ~100 GWh	Diffusion (follows BEV)

Avicenne (2016) assumed that the global sales volumes for HEV will increase from approximatively 1.8 million HEV/year in 2015 to 2.5 million HEV in 2020 (35% lithium-ion batteries), and 3.2 million HEV in 2025 (90% lithium-ion batteries). For BEV, 1.6 million BEV are expected to be sold in 2020, and 2.5 million in 2025 (90% lithium-ion batteries). Anderman (2015) publishes lower forecasts for 2020 (1.9 million unit cells for HEV, 0.85 million unit cells for PHEV and 0.78 million unit cells for BEV sold worldwide). Other forecasts based on different scenarios were published by Blagoeva et al. (2016). According to Anderman, until field data for 2020 confirm reliability, it is risky to forecast sales volumes after 2025. He forecasts that the competitive position of li-ion versus all other technologies will continue to improve.

4.2.2 Portable Electric and Electronic Equipment

The POM data collected in WP3 show that the volumes of zinc-based batteries and NiMH are expected to remain stable or decrease in the next years, but the volumes of lithium-ion batteries increase continuously and are expected to continue growing.

According to Avicenne (2016), the sales volumes of portable devices are expected to increase by 6% per year between 2015 and 2025. Thielmann et al. (2015a) also mention expected market growth rates of 5 to 10%. For instance, the applications of lithium-ion batteries where sales volumes are increasing are mobile phones and other portable electronics (Figure 56). The share of the products classified as “other portable electronics” is significantly increasing, showing a diversification of the usage of the batteries, since a variety of traditionally plugged products like vacuum cleaners are increasingly becoming cordless and use a battery, which is linked to the trends towards digitalization presented in Section **Error! Reference source not found.**.

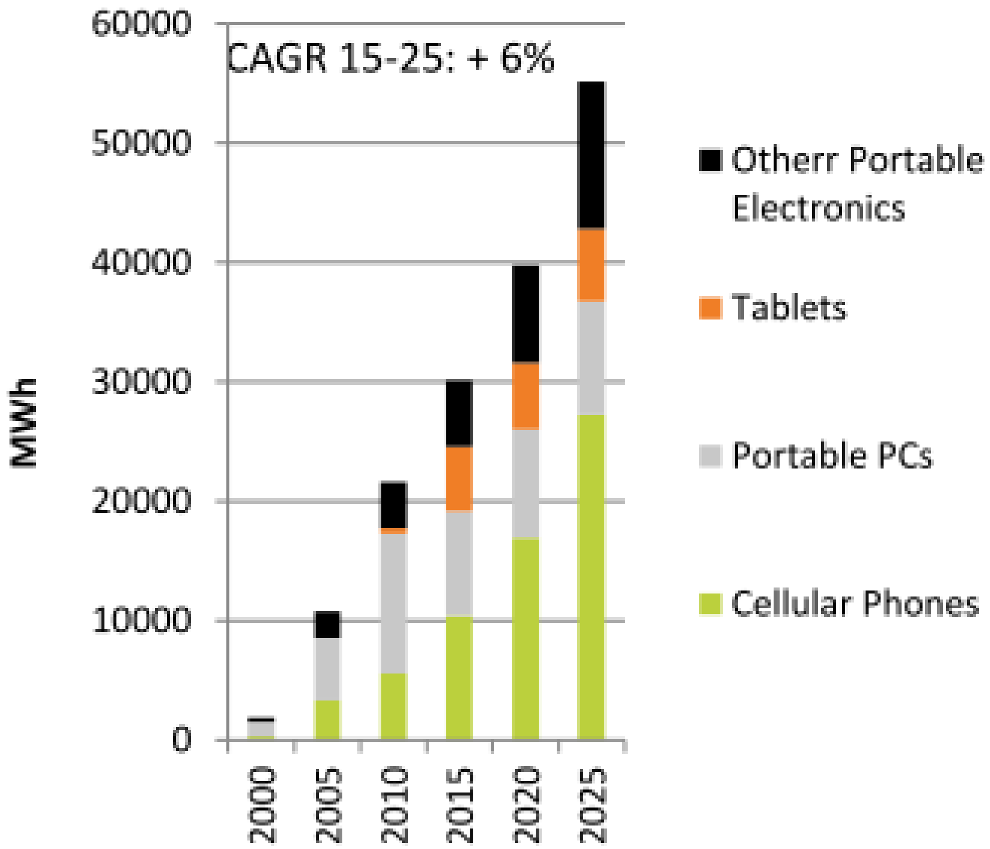


Figure 56: 2000-2025 lithium-ion batteries market, MWh, by application (Avicenne, 2016)

The portable applications, because of their low but steady market growth, can be classified as large and reliable markets, even though the markets for some consumer electronics applications like digital cameras and camcorders are stagnating (Thielmann et al. 2015a). Large numbers from 10 million to several billions of products using Li-ion batteries with less than 100 Wh are sold each year, for instance mobile phones (100 % li-ion batteries), tablets (100 % li-ion batteries) and laptops (100 % li-ion batteries). They represent a 10 GWh markets which are dynamic for tablets and mobile phones. Further portable products using small batteries with markets up to 1 GWh are power tools (50 to 70 % li-ion batteries, increasing), cordless phones (15 to 35 % li-ion batteries, beside Ni-MH), camcorders and video games (100 % li-ion batteries), digital cameras and MP3-Players (90 to 100 % li-ion batteries, beside primary batteries), toys with electronics (40 to 60 % li-ion batteries, beside NiMH and primary batteries) as well as household appliances, and medical devices (Thielmann et al. 2015a).

4.2.3 Energy Storage

Energy storage systems can provide a variety of application solutions along the entire value chain of the electrical system, from generation support to transmission and distribution support to customers (EPRI, 2010). The roadmap produce by Thielmann et al. (2015b) distinguishes between: decentralised photovoltaic battery systems; optimisation of electricity consumption with larger energy storage including peak shaving; direct marketing of renewable energies; and balancing power. According to Avicenne (2016), the market for energy storage systems will increase from 36 GWh in 2015 to 65 GWh in 2025 (Figure 57).

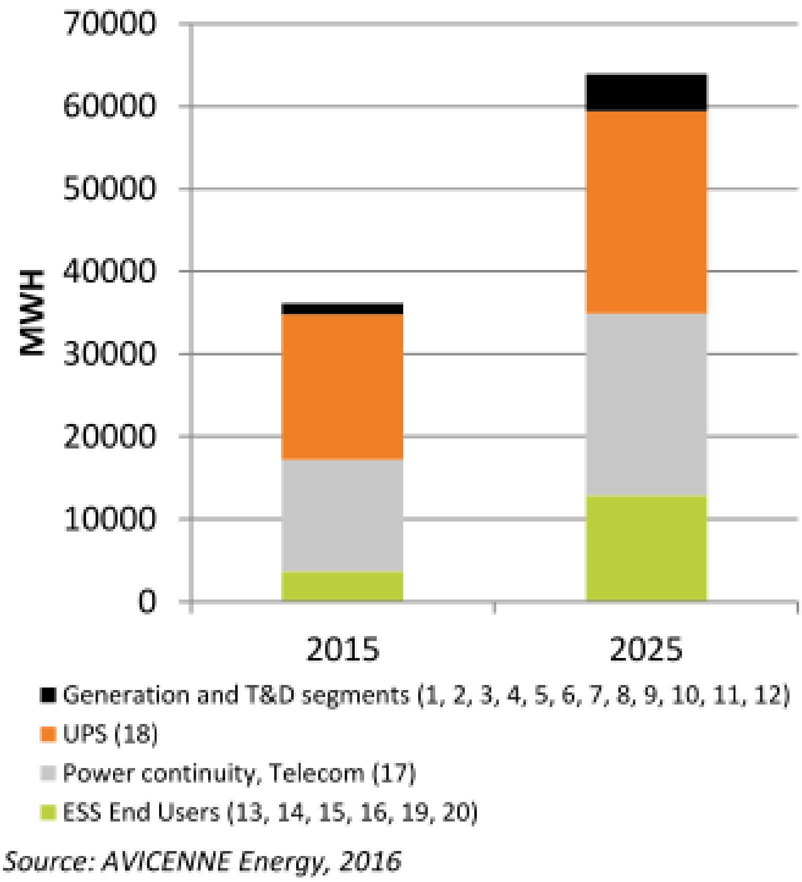


Figure 57: Forecast of the market of energy storage systems (Avicenne, 2016)

The mass production of energy storage systems using Li-ion batteries is expected to be achieved: between 2015 and 2020 for decentralised photovoltaic battery systems, which already entered the market; around 2020 for larger energy storage between 100 kW and 1 MW, direct marketing of renewable energies and balancing power; and between 2020 and 2030 for energy storage over 5 MW (Thielmann et al., 2015b).

Lithium-ion batteries will increasingly replace lead-acid batteries until 2020. Most energy storage systems for decentralised photovoltaic battery systems currently use LFP/graphite-based lithium-ion batteries. Li-ion batteries with NMC, NCA, LCO and LMO cathodes, LFP batteries with LTO anodes and lead-based batteries represent in total less than half of the market (Thielmann et al. 2015b). Thielmann et al. (2015b) list costs, efficiency, cyclical and calendar lifetime, conditions, safety, ambient conditions (temperature), volumetric energy and power density as factors influencing the choice in battery type.

Today, the use of sodium nickel chloride batteries has been broadened from electric vehicles and hybrid electric vehicles to industrial applications, including telecom and back-up markets, as well as on/off-grid stationary energy storage systems for large renewable energy power stations, and supply of ancillary services to the electrical grid (Eurobat 2015). Research is currently being conducted to reduce the heat losses by developing low temperature systems, where mass production may be expected after 2020 (Thielmann et al., 2015b). Also, redox flow batteries with a low energy density such as the vanadium redox flow batteries (VRFB) may be relevant for instance for large stationary storage applications after 2020 (Thielmann et al., 2012b, 2015a, 2015b). EPRI forecasted in 2012 that batteries using the electrochemical systems sodium-sulphur, sodium-nickel chloride, advanced lead-acid and lithium-ion will be deployed in the mature technologies available on the market in 2020 (Figure 58).

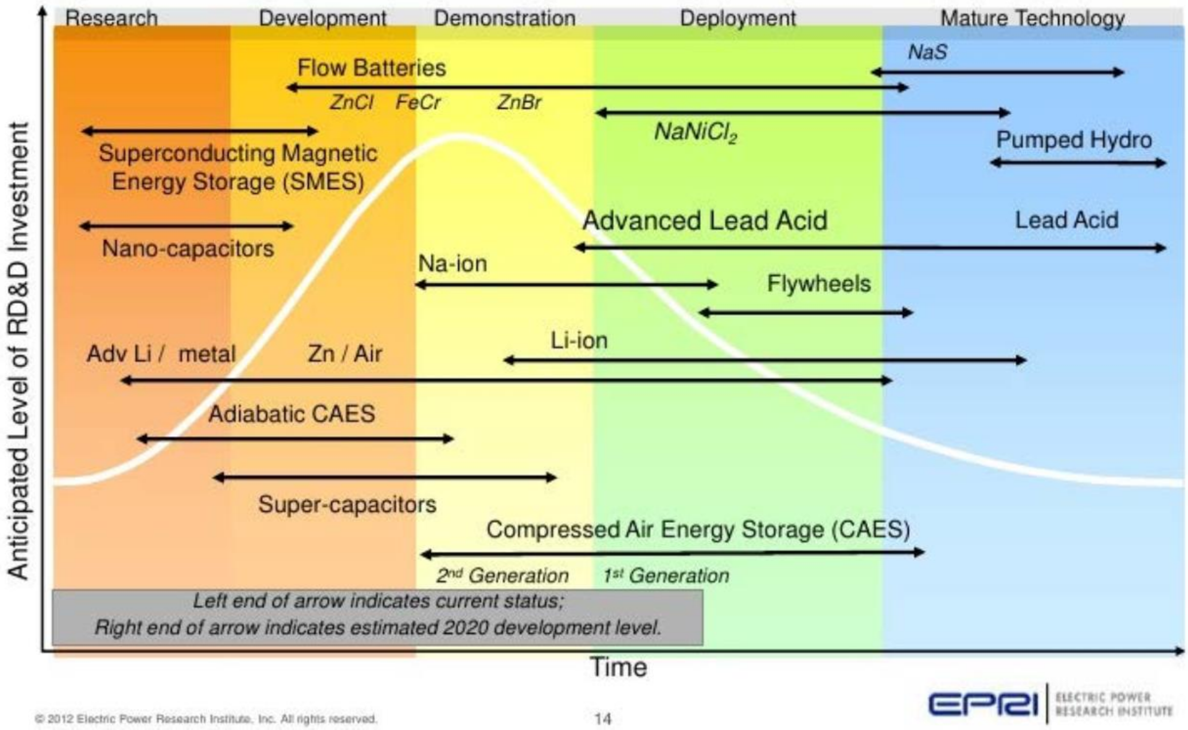


Figure 58: Technology Readiness of Energy Storage Technologies as depicted by EPRI in 2012 and cited by Baxter (2016)

4.2.4 Market maturity

The findings of the market analysis are summarised in Figure 59, which provide a snap-shot of the market penetration for different battery electrochemical systems in the main applications of the sectors electric mobility, portable EEE and energy storage in 2017. The Figure shows the dynamism of the li-ion markets over the three sectors. A limitation of the Figure is that even though the S-curve theory is expected to be applicable to all products, the speed of the progress along the S-curve and the existence of enhancements (Section 1.1.2) cannot be estimated or forecasted with the available data.

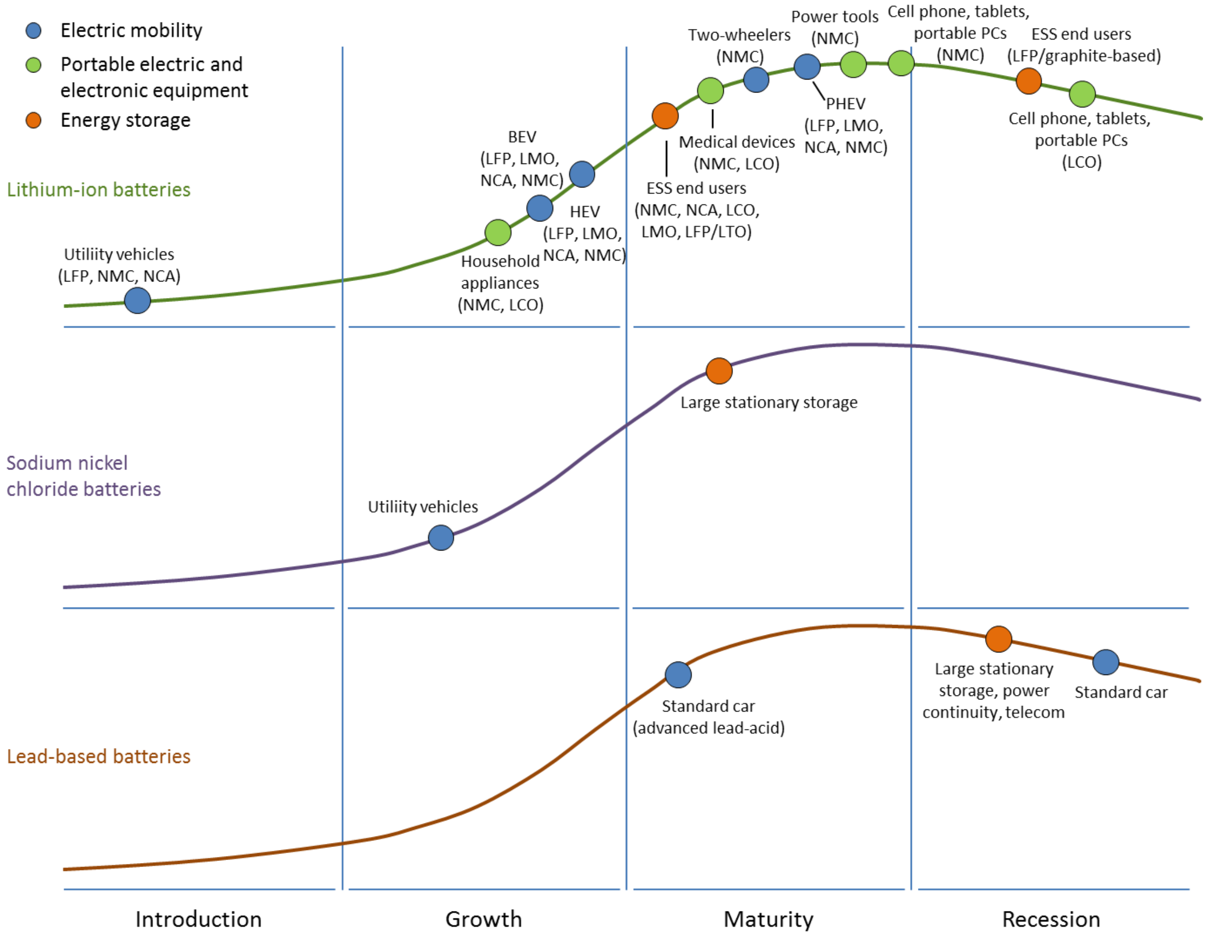


Figure 59: Market penetration of battery electrochemical systems in applications of the sectors electric mobility, portable EEE and energy storage in 2017

4.3 Forecasting CRM parameters

4.3.1 Trends Regarding the Materials for Batteries

According to Avicenne (2016), it takes between 10 and 20 years to commercialize a new material in the battery industry. Recharge (2013) mentions that 10 to 15 years of research and development are necessary after proof of concept to industrialize and commercialize consumer cells, and 15 to 25 years for automotive cells. Figures 60 and 61 illustrate the timescales for past and future market introductions of materials for cathode, anode, electrolytes and separators. Ahlberg Tidblad et al. (2015) mention that based on the same basic principles as the Li-ion concept other types of metal-ion concepts are possible, Na-ion being one of the most attractive metal-ion candidates. Challenges remain before the proof of concept, e.g. concerning the anode materials and air sensitivity. Also, organic electrode materials may be developed in the future (Ahlberg Tidblad et al., 2015). However, in accordance with the fact that no game-changing technologies are currently approaching the consumer market, no abrupt changes in the types of materials used in batteries placed on the market are expected in the short term.

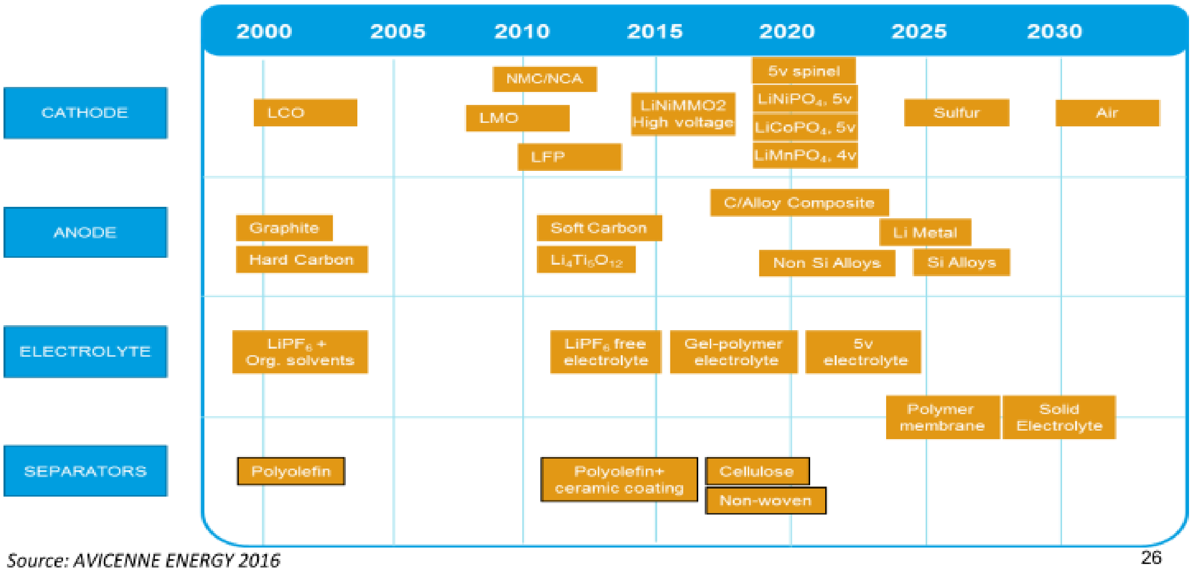


Figure 60: Time to market for new material (Avicenne, 2016)

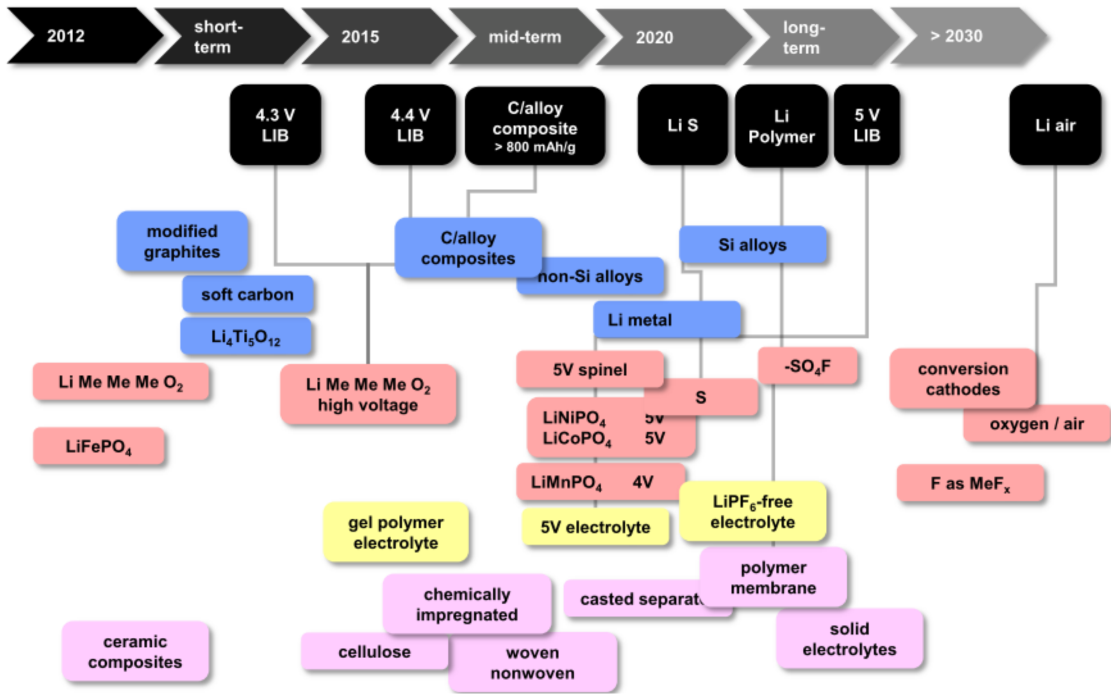


Figure 61: Types of lithium-ion battery cells (Möller, 2013).
Legend: Blue: anode materials; Pink: Cathode materials; Yellow: Electrolytes; Purple: Separators

According to Avicenne (2016), a large increase in the consumption of cathode active materials is expected between 2015 and 2025 (Figure 62), mainly driven by an increase in the sales volumes of NMC batteries. This is due to the increase in sales of battery-containing products and an increasing share of NMC batteries in the batteries sold.

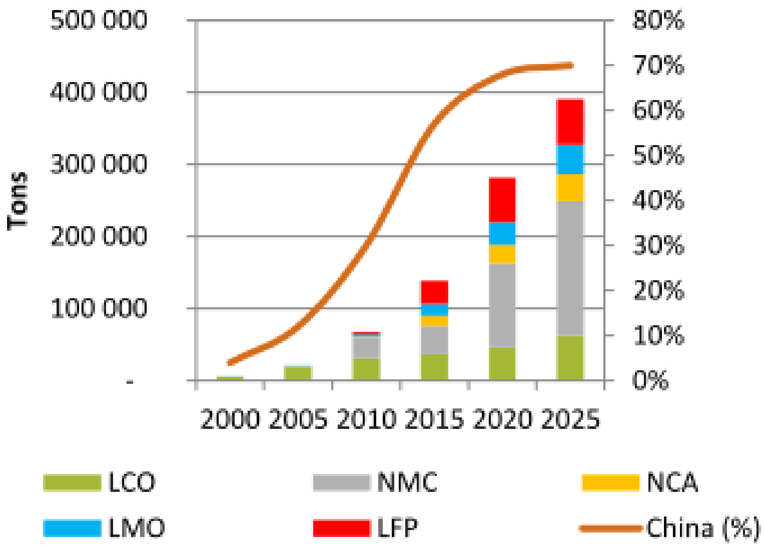


Figure 62: Cathode active materials 2000-2025 – Tons (Avicenne, 2016)

According to Darton (2016), until recently the cathode chemistry of choice for the majority of BEV and PHEV producers was a combination of NMC with a non-cobalt chemistry material, mainly LMO. The spreading trend is that an increasing number of automakers are choosing full NCM chemistry to achieve higher energy density and thus longer distances per charge. Natural graphite ion is the reference anode material for LIB. In comparison to available alternatives (artificial graphite, mesocarbon microbeads, Si and Sn composites/alloys, and lithium titanium oxide (LTO)), natural graphite had a 64 % share in 2014 (Avicenne, 2015). Nevertheless, this market share is linked to cost differentiation as there is little difference in product performance.

4.3.2 Modelling of CRM Consumption in the Literature

Thielmann et al. (2015a) provide estimates of the development of the lithium and cobalt consumption, based on modelling assumptions, e.g. that the raw materials consumption for batteries is 177 g lithium/kWh and 467 g cobalt/kWh in Li-NMC batteries and 119 g lithium/kWh in LiFeP batteries (Reuter et al. 2014), and that the cell demand NMC/ LiFeP was 70%/30%.

Lithium

For lithium, the modelling of Thielmann et al. (2015a) shows that for a scenario with late diffusion of EV, the cumulative lithium use is over 10 million tons until 2050, and for a scenario with early diffusion of EV, up to 23 million tons until 2040. Vehicle batteries are the dominant application, with approximatively 90% of lithium consumption.

Cobalt

For cobalt, the modelling shows that for a scenario with late diffusion of EV, the cumulative cobalt use is almost 30 million tons until 2050, and for the early diffusion of EV, over 50 million tons until 2040. Vehicle batteries are also the dominant application for cobalt. The modelled demand for cobalt exceeds the available resources. The estimates can be reduced to 15 (late diffusion) and 20 (early diffusion) tons of cobalt by technical progress reducing the cobalt use in batteries. The modelling does not consider the use of non-cobalt containing batteries. Cobalt being one of the highest value components in batteries, it is also expected that a high level of recovery of this metal will occur through recycling.

4.3.3 Substitution

Regarding substitution of CRM, assumptions made by Blagoeva et al. (2016) are shown in Table 10. Blagoeva et al. assume that no efforts are anticipated to substitute Li in batteries. For cobalt, it is difficult to foresee how many batteries will contain less or no Co at all by 2030.

Various combinations of Ni, Mn and Al and other materials can be used to replace some of the Co. Blagoeva et al. (2016) assumed a substitution rate of around 26% for Co until 2030. Today, more than 50% of batteries use natural graphite, which can be substituted with synthetic graphite, amorphous carbon, or Si-Sn carbon composites.

Table 10: Li, Co, graphite global substitution rates (Blagoeva et al., 2016)

Materials	2015	2020	2025	2030
Li	0	0	0	0
Co	0	4	15	26
Graphite	0	15	28	38

4.3.4 Case study CRM in Waste Batteries from Electric Vehicles

A case study on electric vehicles has been used as it is expected that electric mobility will become the largest application for lithium-ion batteries in 2025 (Avicenne, 2016). The case study aims to estimate the amounts of cobalt available for recycling in future years.

To conduct modelling of waste flow generation, data on the number of electric vehicles put on the European market from the ICCT for the years 2005-2015 were used. For the years 2015-2020, a market increase of 16% was assumed for BEV and PHEV, and an increase of 6% for HEV. These data on POM volumes were combined with data on the average weight of batteries in BEV, HEV and PHEV and on the shares of the different electrochemical systems used in the batteries of the three types of electric vehicles. These data were compiled by RECHARGE and based on the annual Avicenne market studies. Figure 63 shows the numbers of lithium-ion batteries NMC and LiMn, as well as of NiMH batteries, put on the market in BEV, HEV and PHEV between 2005 and 2015.

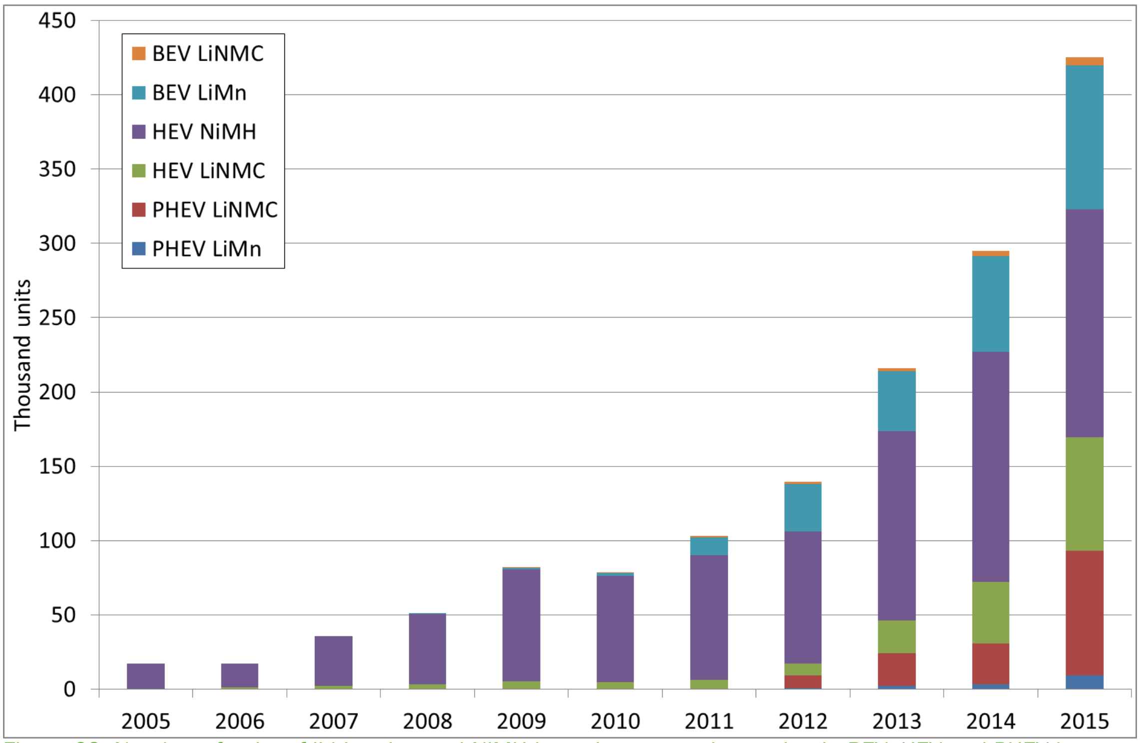


Figure 63: Number of units of lithium-ion and NiMH batteries put on the market in BEV, HEV and PHEV between 2005 and 2015

Experimental data on the lifespan distribution of batteries in electric vehicles are not available. A Weibull distribution with a shape of 2 and a scale of 10 were assumed, resulting in an average lifetime of around 9 years. The modelling was conducted as explained in Deliverable 2.3 and provided estimates for the generation of waste batteries in units (Figure 64 64) and tonnes (Figure 65) until 2023. The Figures show that in terms of units, NiMH batteries from PHEV are the most relevant flow of waste batteries until 2017. In 2023, LiMn batteries from BEV, NiMH batteries from PHEV and LiNMC from HEV and PHEV are expected to have similar volumes in units. The LiMn batteries from BEV make out most of the weight.

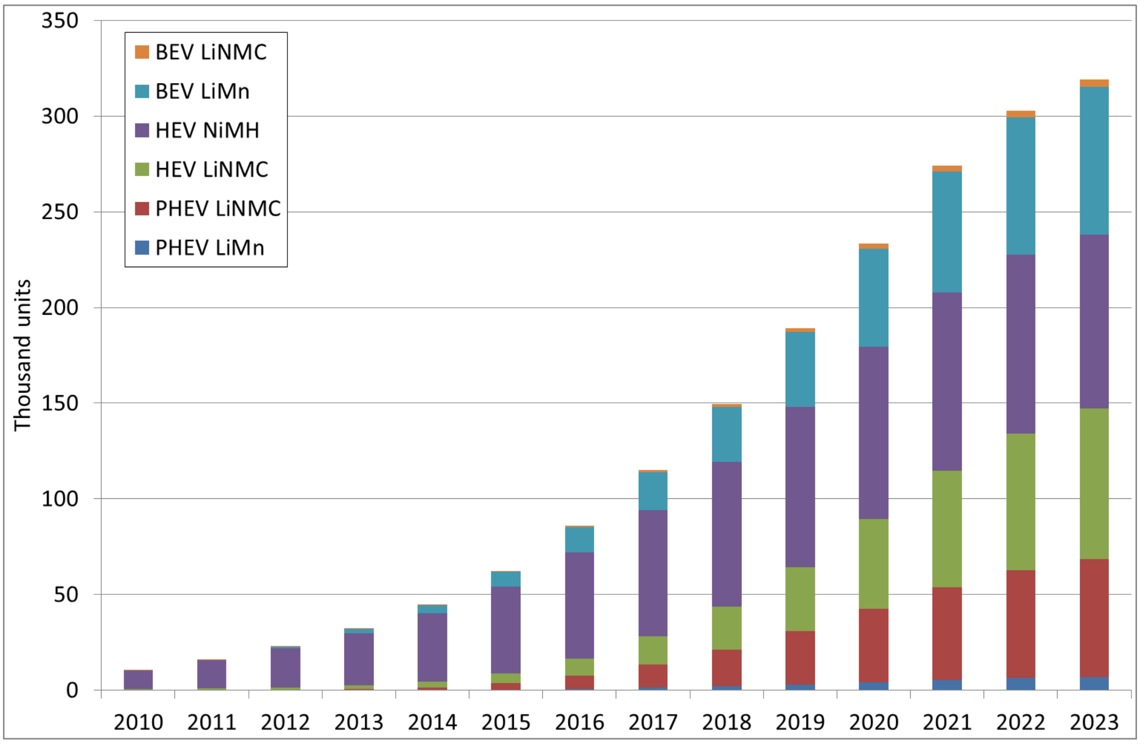


Figure 64: Estimates of the generation of waste batteries from electric vehicles in units until 2023

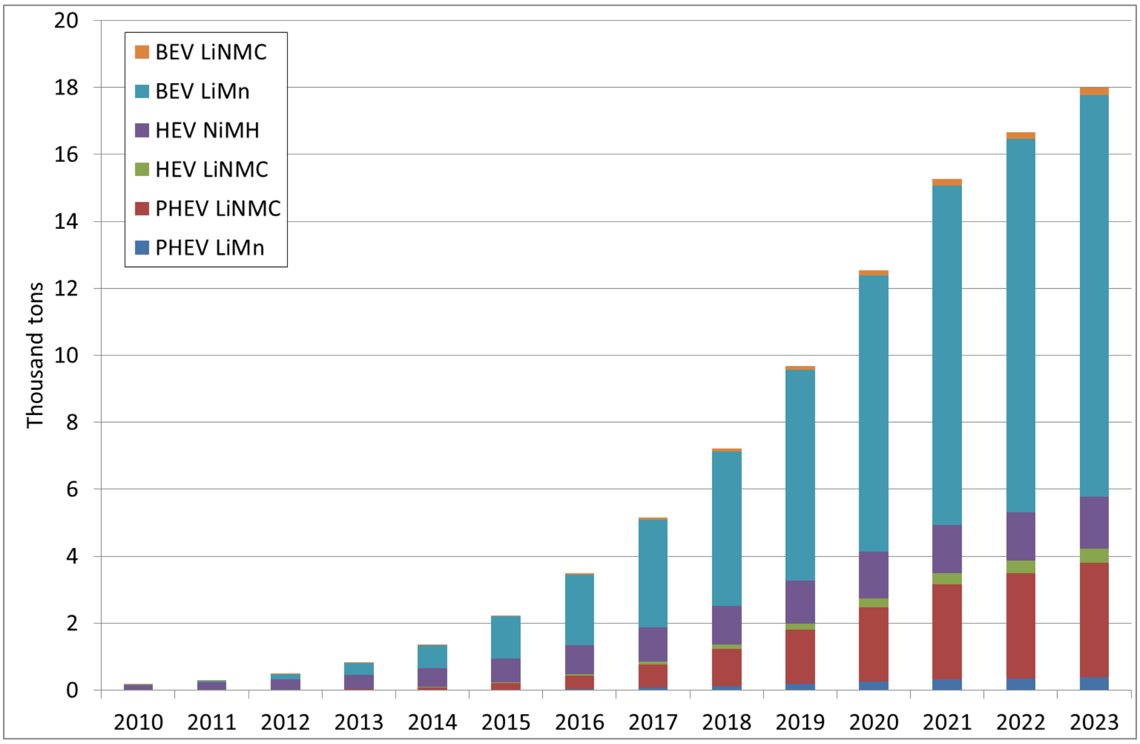


Figure 65: Estimates of the generation of waste batteries from electric vehicles in tonnes until 2023

The cobalt content is, according to the data collected in Task 2.5, around 4% in li-ion NMC batteries, and 3% in NiMH batteries. LiMn batteries do not contain cobalt. The modelling shows that from 2018, most of the cobalt contained in waste batteries from electric vehicles is embedded in the LiNMC batteries that were used in PHEV (Figure Figure 66).

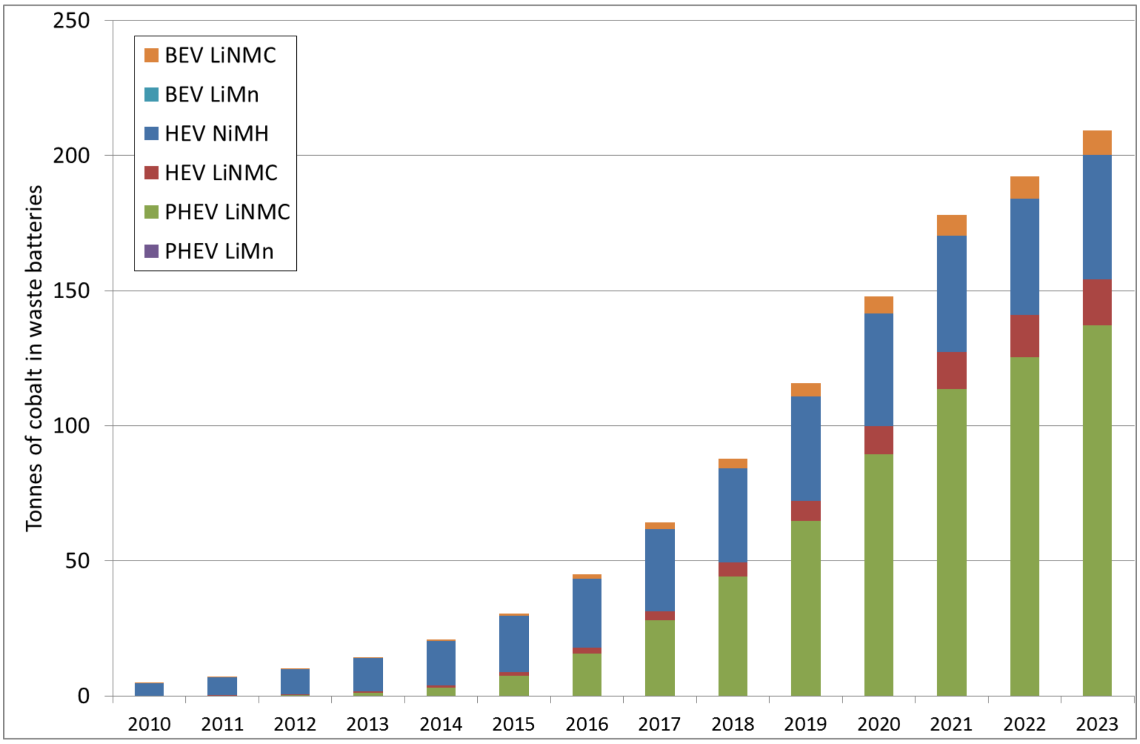


Figure 66: Estimates of the amount of cobalt contained in the generated waste batteries from electric vehicles

4.4 General Battery Trends

Data are available for the three relevant future battery markets: the development of the product markets of products that contain batteries; the electrochemical systems used in the batteries; and their material composition, for instance their CRM content.

The available studies provide quantitative results for future trends for products containing batteries that differ on the details but agree in terms of overall qualitative trends. There will be increased demand for batteries for electric mobility, for instance for BEV and PHEV. How high this increase will be, depends on many socio-economic and policy-related factors that can't be predicted in the long-term. As Anderman (2015) states, until field data for 2020 confirm reliability of the available forecasts, it is risky to forecast sales volumes after 2025. The demand for batteries for energy storage systems will strongly increase. The market for portable batteries will also increase with rates depending on the products. A diversification in the usage of batteries related to the digitalisation of many products will result in the development of new markets. Other markets will decline, as a consequence of the convergence of products (e.g. digital cameras and MP3 players integrated in smartphones)

For all three sectors, li-ion technologies have the most competitive position and that this is not expected to change before 2025. However, li-ion is a very heterogeneous group of battery technologies and the materials used vary. The cobalt-rich cathode material LCO is being replaced by NMC and NCA that contain less cobalt than LCO. For some applications, the cobalt-free cathodes LCO and LFP are being used. The available data seem to predict that despite the shifts from cobalt-rich to less cobalt-rich electrochemical systems, the increased demand for batteries is expected to result in an overall increase in cobalt demand. Moreover, the diversity of the material combinations will increase, as a consequence of the diversity of the materials available for all four components of a battery cell (cathode, anode, electrolyte and separators). This gives high flexibility to meet the technical requirements for batteries but also results in batteries that have very diverse material compositions, and in more complex flows of waste batteries.

5 Conclusions and Recommendations

5.1 EEE Conclusions

The use of materials in the design and production of electronics is evolving rapidly over time. Currently, there are major trends in more products becoming ‘smarter’, smaller and more multifunctional. This significantly affects the design and material composition of new products. The main driver behind this is increasing functionality and complexity in components related to the domains of Mobility, Control, Power Generation, Sensing, Communication, Computation and Human Interface. The increased application of these components with complex material composition impacts on secondary raw materials arisings and consequently recycling potential.

Table 11: UNU key specific trends for new products in the adaptation curve

UNU Key	WEEE Directive Collection Category	Device type	S Curve			
			Innovators	Early adopters	Early majority	Late majority
0002	V. Small equipment	PV tiles				
0108	I. Temperature exchange equipment	Smart Refrigerator				
0112	V. Small equipment	Thermo mix-cooker				
0201	VI. Small IT	Smart watch				
0201	V. Small equipment	Wireless charging station				
0201	V. Small equipment	internet of thing (IoT) devices (not lamps, not otherwise classified)				
0202	V. Small equipment	Slow cooker				
0204	V. Small equipment	Robot vacuum cleaner (e.g. Roomba)				
0301	VI. Small IT	Next gen fiber/dsl routers				
0302	VI. Small IT	All-in-One (AIO) Desktop (Diplay plus UCP)				
0304	VI. Small IT	3D printer				
0306	VI. Small IT	Smartphone accessories				
0401	V. Small equipment	Portable battery pack				
0402	V. Small equipment	Rear view & Dashboard cameras (not build-in)				
0405	V. Small equipment	Wireless audio streaming (e.g. Sonos)				
0406	V. Small equipment	3D camera				
0406	V. Small equipment	4K video camera				
0406	V. Small equipment	Surveillance (wifi cameras, with(out) smart sensors)				
0408	II. Screens	3D display devices				
0408	II. Screens	Flexible screens				
0408	II. Screens	UHD 4K TV				
0408	II. Screens	Smart TV				
0408	II. Screens	OLED screen				
0601	V. Small equipment	Solar chargers				
0601	V. Small equipment	Robot lawn mower				
0701	V. Small equipment	Drones				
0702	VI. Small IT	Augmented reality headset				
0702	VI. Small IT	VR headsets				
0702	VI. Small IT	Next-gen gaming consoles				
0702	VI. Small IT	Gaming accessories				
0703	IV. Large equipment	Electric skateboard/scooter				
0703	IV. Large equipment	Hoverboard				
0703	IV. Large equipment	E-bikes				
0703	IV. Large equipment	Segway				
0703	IV. Large equipment	Health & fitness trackers				
0801	V. Small equipment	Home diagnostic (BP, Glucose, EEG etc.)				
0801	V. Small equipment	Smart prosthetics				
0901	V. Small equipment	Security and remote start systems (e.g. keyless doorknob)				
0901	V. Small equipment	Electronic tags/readers				
0901	V. Small equipment	Sensor controlled devices				
1001	IV. Large equipment	Personal robots				

Utilizing available information from literature, through the analysis and application of diffusion curves and analysis of trends, the link between the product and material trends for total secondary raw materials availability in stocks and flows has been established. A summary of trends for new EEE products is presented in Table 11 above. The device types listed will have increasingly diverse composition, utilizing more CRMs but in smaller quantities per device.

A more quantitative summary of the forecasting for EEE product amounts for 2016-2020 is given in Table 12, with the exception of compact fluorescent lamps (UNU Key 0502), all UNU keys in the middle income stratum will grow by number of products, while due to saturated markets in the high income stratum 0.7-2.4% growth rate is expected. This differentiation between income strata gives an indication of product take up and saturation potential.

Table 12: UNU Key extrapolation from 2016-2020

Example UNU key	Collection category	Type of extrapolation 2016-2020	Average growth rate 2015-2020 stratum HIGH	Average growth rate 2015-2020 stratum MED	Average growth rate 2015-2020 stratum LOW
0108	I	Replacement market	1.3%	3.5%	0%
0408	II	Market saturated	0.7%	9.3%	9.7%
0502	III	Exponential decline	Not for sale in coming years	Not for sale in coming years	Not for sale in coming years
0102	IV	Replacement market	2.4%	3.3%	0%
0204	V	Market saturated	2.3%	5.7%	0%
0702	VI	Replacement market	1.1%	8.9%	0%

A more comprehensive overview of newly appearing and also disappearing products has been constructed in the form of the UNU Key Catalogue. This catalogue provides an overview of all UNU keys, listing the product type, key parameters and product specific market trends. It serves as a visual instrument and provides sample pictures of the most common products. This catalogue is also intended as the basis for later visualization and background information for users of the EU-UMKDP portal and is displayed in Annex I.

Finally, for the WEEE collection category Screens, the entire multiplication of past and future products trends, the components used and the total material content has been calculated for gold as an example element. This calculation work is being further expanded for all components and materials present in WEEE for inclusion in the EU-UMKDP.

5.2 Vehicle Conclusions

Historic and current trends for fleets and vehicle designs have been used to identify the CRMs which will be generated in ELV flows at present and when vehicles put on the market today will on average reach their end-of-life. It has also been possible to make some assumptions about ELV flows further into the future based on current intelligence about the future development of the vehicle fleet and car designs. Quantified estimates of the total mass of CRMs in vehicle stock and flows are not provided in this report but will be generated as part of coming work in ProSUM.

Overall, it is expected that the total mass of the vehicle stock and consequently ELVs generated annually will increase slightly over the coming years. This is due to the observed increase in the number of vehicles in the stock and their average mass. The median age of a vehicle is estimated to be around 14 years based on data for the last 15 years, implying that the median vehicle recycled today was manufactured in 2003, and, conversely, that half of all vehicles manufactured in 2017 will reach end of life by 2031.

The diesel boom in the 2000s will lead to a higher share of diesels in generated ELVs in the coming years. In the longer term, however, diesels may come to constitute a smaller share of ELVs if, as currently expected, their market share decreases due to increasing problems with particulate matter emissions in European cities.

Electrified vehicles will constitute a small minority of ELVs for a long time. They started to come onto the market around ten years ago, and even if sales now increase rapidly, they currently represent around 3% of vehicle sales. HEV still dominate sales, while PHEV and BEV took off a few years ago. Since sales are concentrated to a few countries, such as Germany, Norway, France and the Netherlands, it may be expected that EVs in ELV flows will be fairly concentrated to certain countries too.

The distribution of different EV drivetrains affects the quantity of CRMs in the ELV flow. PHEVs with Li-ion battery typically require significantly less lithium, copper and REE, but more cast aluminium (combustion engine) and PGMs (catalytic converter) than a BEV with Li-ion battery.

It is clear that the share of steel in cars has been decreasing and substituted by aluminium, magnesium and plastics. Furthermore, steel types have shifted towards more high-strength and advanced high-strength steel.

In terms of CRM quantities in the ELV flow, the shift of steel types may have had a relatively small impact, although some increase in niobium and molybdenum is likely.

Only a small increase in cast aluminium content is expected in the coming years, as its use in new vehicles has only grown slowly in the past decade.

With the rapid increase of wrought aluminium use, magnesium as an alloying element is also increasing. Other CRM alloying elements are also in use but such information is largely lacking. In the coming years, the amount of wrought aluminium in ELVs will increase substantially but cast alloys will retain the largest share of aluminium scrap. Magnesium alloys have also increased their share in vehicles over the last ten years to a lesser extent than aluminium. If trends continue as predicted, magnesium as an alloy and as an alloying element in aluminium, will further increase in ELV flows in the longer term.

The late introduction of catalytic converters for diesel cars combined with the European diesel boom in the 2000s will lead to a significant increase in platinum arising from ELVs in coming years. In the longer term, however, it is currently expected that diesels will decrease. Also, any electrified drivetrain will reduce the need for catalytic converters and related content of PGMs and REEs. Furthermore, there are continued efforts to substitute PGMs in catalytic converters due to their high cost. In summary, it may be expected that at least over the next 15 years, the amount of PGMs and REEs in catalytic converters will increase in ELV flows. It could be expected that these arisings eventually will peak and then stabilize or decline, dependent upon the future balance between stricter emission targets, and the substitution of PGMs in catalytic converter material, the phase out of diesel engines and the introduction of electrified vehicles.

The inclusion of EEE in vehicles has increased significantly over the last years and will be readily observed in flows of ELV fairly soon. As an example, a rough estimate based on these numbers would indicate that the amount of gold and neodymium per ELV could increase by 2 and 10 times respectively in the next 10-20 years (Restrepo et al. 2017). In the longer term, the level of EEE and associated CRMs in ELV flows are likely to be higher than today. There are indications that integration of components may reduce or even slightly reverse this increase. However, an increase in electrified drivetrains will involve substantial increases in EEE. This will constitute a small share of ELV flows, possibly concentrated to a few countries, for a long time.

5.3 Battery Conclusions

The CRM containing components in batteries are rare earth elements in NiMH batteries, cobalt in the cathode materials LCO and NMC/NCA and natural graphite in the anode. NiMH batteries are being replaced by lithium-ion batteries, which is a very heterogeneous group of electrochemical systems using a high variety of material combinations. Lithium-ion batteries offer currently the most competitive electrochemical systems in the three most dynamic sectors of products containing batteries: electric mobility, energy storage systems and portable equipment. This position is not expected to change in the next years, even though research is being conducted to develop and improve other technologies like sodium nickel chloride batteries.

Battery markets depend on the development of markets for battery-containing products. Decisions taken by the battery producers relate either to the selection of the type of electrochemical that will be used in the products, or its material composition. These decisions heavily impact on the consumption of CRM. Two interlinked strategies are possible to limit or reduce the CRM demand for batteries:

- Select battery systems that do not contain the CRM-containing components, e.g. with sodium nickel chloride batteries or lithium-ion batteries with LFP or LMO cathodes; or
- Reduce the CRM concentrations in the CRM-containing components.

The implications for CRMs across all three application areas are that:

- Electric Vehicle demand growth is expected to attract the interest of large chemical companies;
- New materials are likely to be needed to meet expected Automotive standards; and
- Lead acid batteries will be largest market in 2025 both in terms of volume and value.

It can be foreseen that there will be a shift from CRM containing batteries NiMH (REE) and $LiCoO2$ (cobalt) to batteries containing less CRM (NMC), with the market diffusion of batteries containing no CRM (sodium nickel chloride batteries).

5.4 Final Conclusions

The purpose of this report is to generate insights for expected development in products and their material composition. This report provides reasonably reliable projections on future factors for CRM parameters concerning the composition of products and components. Furthermore consideration is made of the market drivers for materials entering the urban mine in products and equipment. This allows for a more considered appraisal of materials entering waste streams but may also facilitate consideration of material choices made in design and manufacturing. This would require further work and analysis and is not provided for in ProSUM.

The results presented here support the need to construct a comprehensive inventory identifying, quantifying and mapping CRM stocks and flows at national and regional levels across Europe. The identification of trends assists by identifying where caution needs to be given to long term waste arisings and material generation and where there is need for further work. The methods and techniques encountered and tested, have been used to develop a framework for predicting and modelling future scenarios for CRM parameters.

Work undertaken in D2.3 to identify the factors in the trends of CRM parameters in products and components in the short term, has been analysed together with data on products POM in the past and resulting in waste flows, and taking into account disruptive technology developments.

A range of product based graphs in the form of curves, adoption curves, S-curves and Gartner's Hype cycle are commonly used in product development and marketing to establish sales and market penetration. These graphs have then used together with literature on critical materials composition in products, to help develop CRM trends in products.

The findings for EEE, vehicles and batteries show a correlation between the curves and the application of materials which allows for examples of short term trends in CRM parameters, to be presented.

The results of this deliverable will be utilized in WP3 to model stocks and flows of CRMs to create the CRM inventory and in the development of future scenarios to assist in the development of services and features for the EU-UMKDP.

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7 Annexes

7.1 Annex 1 EEE Product Catalogue

Explanation

<Listed are the most common appliances falling under this UNU key>

POM means placed-on-market as new appliances. The most common appliances are listed

Here is the typical range of average weight per unit when placed on the market

Here is the typical share of the appliances to the total POM. Note: the numbers can be very country dependent

Collected represent the appliances that are collected as waste. The most common applainces are listed

Here is the typical average weight per unit when collected

Here is the typical share of the appliances to the total Collected. Note: the numbers can be very country dependent

Example picture for the appliances (note: where brand names are visible, there are chosen randomly and are by no means prviding a preferene for a certain brand)

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)
1	(Combi) electric boilers	29 - 53	55%	(Combi) electric boilers	56	95%
2	Boiler	36 - 60	40%	Tank-less water heaters	9	< 5%
	New products :			Disappearing products:		
				Traditional geyser (non-electric)		

Example of new types of appliances that are placed on market

Example of appliances that are dissapearing from the market

Visual illustration

1

2

Market entry

Median residence time*: 12 years

Market exit

This is the average time for half of the appliances leaving households and businesses together (differs from first use, also 2nd use and hibernation is included)

Some values are rather uncertain and estimated

Some values may vary significantly from country to country

* The numbers for these products vary significantly per country

** Numbers in red are estimated

0001 Household Central Heating

Household installed boilers (with or without copper tank), boiling water tap, combi boiler, geothermal heat-pumps, gas-electric heating systems, geyser, heat exchangers, heat pump boiler, tank-less water heaters, other boilers, VMC

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)
1	(Combi) electric boilers	29 - 53	55%	(Combi) electric boilers	56	95%
2	Boiler	36 - 60	40%	Tank-less water heaters	9	< 5%
	New products :			Disappearing products:		
				Traditional geyser (non-electric)		

1

2

3

Market entry

Median residence time*: 12 years

Market exit

* The numbers for these products vary significantly per country

0002 Photovoltaic Panels

Inverter (for PV panels), PV panels (other types), PV panels (roof-mounted), home electricity storage systems, Inverter

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1, 2	PV panel	18	95%	PV panel	24	80%
3	Inverter	10	5%	Inverter	7	20%
	New products :			Disappearing products:		
4 5	PV tiles Home electricity storage system					

Market entry — Median residence time*: 20 years — Market exit

ProSUM

* The numbers for these products vary significantly per country

** Numbers in red are estimated


1

2

3

4


5

0101 Professional Heating & Ventilation

Heat recovery units, large professional heating appliances, professional kitchen appliances (non-cooled), radiation panels, terraces heaters, other heat heating equipment

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	Heat recovery unit	8.0 – 250	60%	All professional heating appliances	25 - 75	100%
2	Industrial Ovens	7.8 - 120	15%			
3	Terrace heaters	4 - 15	5%			
	New products :			Disappearing products:		
4	Geothermal heat pumps					

Market entry — Median residence time*: 14 years — Market exit

ProSUM

* The numbers for these products vary significantly per country


1


2

3

4

0102 Dishwashers

Dishwashing (dishwashers), professional dishwashers, dishwasher with combined cooking hob

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	Dishwasher	37 - 50	100%	Dishwasher	49	100%
	New products :			Disappearing products:		
2	Dishwasher with combined cooking hob					

Market entry — Median residence time*: 13,2 years — Market exit

ProSUM

* The numbers for these products vary significantly per country


1

2

1

1

0103 Kitchen

Built-in oven, conventional cooking hob, cooking equipment, combi-cookers, electric spit used to cook chicken, electrical stove, furnaces, gas stove with electric connection, non-electric gas stove, ovens, Professional stainless steel stove, wood stove with thermostat

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	Combined cooker (incl. or excl. gas)	41 - 71	55%	(Combined cooker (incl. or excl. gas)	59	90%
2	Oven	20 - 42	35%	Oven	46	10%
	New products :			Disappearing products:		

Market entry — Median residence time*: 16,1 years — Market exit

* The numbers for these products vary significantly per country

1

2

2

2


0104 Washing Machines

Washing machines, washing machines + combi-dryers, portable washing machine

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	Washing machines	62 - 84	100%	Washing machines	47	95%
2	Washer-dryer	N.A.		Portable washing machine	6	< 5%
	New products :			Disappearing products:		
3	– Wi-Fi/Intelligent washing machine – Microwave washing machine – Lupe Handheld washing machine – Dismount Washer, Wash $ Go Laundry (using High pressure steam instead of water) – Washing machines w. nano-technology, UV-c or ozone – Orbital washing machine (rotates + pivots on two axes)					

Market entry — Median residence time*: 11,0 years — Market exit

* The numbers for these products vary significantly per country

1

2

3


0105 Dryers

Centrifuges, dryers, tumble dryers

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	Tumble dryer (all types)	36-61	100%	Tumble dryer (without heat pump)	34	100%
	New products :			Disappearing products:		
4	- Heat pump tumble dryer					

Market entry — Median residence time*: 15,0 years — Market exit

* The numbers for these products vary significantly per country

1

Spin dryer


Portable dryer
4


0106 Household Heating & Ventilation

Convector heater fixed, fan coil (for heating and cooling in hot or cold water), fan standing or on foot, hoods, household room ventilation (fixed), immersion heater (resistive heater), radiator / convector, room heaters (non-central), ventilators, VMC (mechanical ventilation)

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	Hood (with motor)	10 - 17	50%	Electric heater, convector	5	70%
2	Electric Heater	2 - 175	10%	Hood, filter assembly	8	20%
3	Axial fan	0.01 - 18	10%	Fan standing or on foot	2	10%
	New products :			Disappearing products:		

Market entry — Median residence time*: **11** years — Market exit

* The numbers for these products vary significantly per country


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3


Extractor fan

0108 Fridges

Absorption fridge, fridges (incl. combi freezers), bio robot refrigerator, eco-friendly verdant refrigerator, portable fridge, refrigerator < 40 kg, refrigerator > 40 kg, smart refrigerator, wine cellar > 40 kg, wine cellar< 40 kg, wine fridge

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	(Combined) Fridge-Freezer	32 - 175	90%	(Combined Fridge-Freezer	31-58	95%
2	Wine fridge (cabinet)	9 - 71	<5%	Wine fridge	13-73	< 5%
	New products :			Disappearing products:		
3	- Bio Robot Refrigerator - Smart Refrigerator - Eco-friendly Verdant refrigerator - Urban Cultivator/ Garden Grower			- Compressor refrigerators (CFCs/HCFCs/FCs/HFCs)		

Market entry — Median residence time*: **14.0** years — Market exit

* The numbers for these products vary significantly per country


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0109 Freezers

Freezer (freezers for food, ice, etc.)

POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
Freezers	37 - 61	100%	Freezers	31 - 61	100%
New products :			Disappearing products:		

Market entry — Median residence time*: **21.0** years — Market exit

* The numbers for these products vary significantly per country


Industrial freezers


Portable freezer


Chest freezer

0111 Air Conditioners

Air condition wall or mobile monoblock, dehumidifying, household air conditioning (fixed, split system), household air conditioning (moveable), other air conditioning

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	Air conditioning, excl. split systems	20 - 36	50%	Air conditioning total	19	100%
2 3	AC indoor unit split syst.	10 - 42	40%			
4	Air conditioning, portable	8 - 15	10%			
	New products :			Disappearing products:		
	Smart air conditioners					

Market entry — Median residence time*: 17.4 years — Market exit

ProSUM

* The numbers for these products vary significantly per country



1 2


3 4

0112 Other Cooling

Heat-pump boilers, Heat-pump dryers, household watercoolers, household ice-cream maker, ice (cube) makers, Thermo-mix cooker with cooling circuit, Beer tender/ice cube machine/electric cool box

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	Dehumidifier	8 - 15	65%	Monobloc heat pump	23	40%
2	Watercooler	3 – 5	25%	Dehumidifier	12	20%
3	Ice maker	6 - 15	10%	Beer machine (without refrigerant)	6	20%
	New products :			Disappearing products:		
4	Thermo-mix cooker					

Market entry — Median residence time*: 12 years — Market exit

ProSUM

* The numbers for these products vary significantly per country



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3 4

0113 Professional Cooling

Commercial refrigeration: cold cabinet, restaurant freezer, cooling displays, parts of Gem F (compressor gem f, fridge door ...), professional fridges and freezers, professional ice makers, other professional kitchen cooling and freezing, professional watercoolers.

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	Refrigerated cabinets and counters	50 - 200	50%	Commercial refrigeration: refrigerated cabinet	47.34	90%
	Refrigerator / freezer unit	100 - 180	20%	Commercial refrigeration: cold cabinet	1.93	5%
	Ice makers	21-200	10%	Commercial refrigeration: Freezer restaurant	1.40	5%
	New products :			Disappearing products:		

Market entry — Median residence time*: 12 years — Market exit

ProSUM

* The numbers for these products vary significantly per country



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0114 Microwaves

Build-in microwaves, combi-microwave, microwave (non-combi), microwave oven

POM	Average Weight (kg/unit)	% p-f (weight)	Collected	Average Weight (kg/unit)	% p-f (weight) *
Microwave (incl. combined)	14 - 31	100%	Microwave oven	14	100%
New products :			Disappearing products:		


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Market entry → Median residence time*: **14,4** years → Market exit

* The numbers for these products vary significantly per country

0201 Other Small Household

Alarm clock, clock radio, clocks, aroma diffuser, electrical air freshener, dry towel, electric blanket, electrical dish-warmer, electrical thermometer (others than medical), electronic waste bin, humidifier, irons, other non-hazardous electrical waste (specify), other small ventilation, sewing machine, small pet electric automatic water dispenser, ironing active robot, Ironing Press, ventilators (small), stopwatch

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	Irons	0.44 - 2.8	30%	Irons	5	60%
2	Sewing machines	5.3 - 7.6	20%	Sewing machines	9	15%
3	Clocks	0.01 - 0.45	10%	Clocks	1	10%
	New products :			Disappearing products:		
4	- Smart watch					


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Market entry → Median residence time*: **6,0** years → Market exit

* The numbers for these products vary significantly per country

0202 Food

Blending and mixing, bread maker, chopper, eggbeater (mixer), electric kitchen sharper, can-opener, electric coffee mill, electric fondue device, fryer, hot dog maker, juice maker, electrical barbecue, mini-oven, nut and vegetable grater, pancake maker, toaster, vacuum food packaging machine, waffle maker, warm food appliances.

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	Cooking hob	10 - 14	20%	Mini-oven	8	30%
2	Fryer	2.0 – 4.7	20%	Fryer	3	10%
3	Grill/ mini-oven	1.6 - 10	20%	Toaster	1	10%
4	Mixer/ blender	0.5 – 5.6	15%	Conventional cooking hob	7	10%
	New products :			Disappearing products:		
5	- Slow-cooker			- Cooking hobs		


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Market entry → Median residence time*: **9,3** years → Market exit

* The numbers for these products vary significantly per country

0203 Hot Water

Bottle warmer, coffee machine, professional coffee maker, ccoffeemakers, expresso machine, kettle, other hot water and steam, other hot water and steam, water cookers.

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	Coffee machine	0.74 – 4.0	40%	Coffee machine	1	50%
2	Espresso maker	2.4 - 18	30%	Expresso machine	3	40%
3	Kettle	0.68 - 1.3	20%	Kettle	1	10%
	New products :			Disappearing products:		

Market entry → Median residence time*: 6,0 years → Market exit

ProSUM

* The numbers for these products vary significantly per country


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0204 Vacuum Cleaners

Handheld vacuum cleaner, household vacuum cleaners, other vacuum and carpet cleaners, rechargeable vacuum cleaner

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	Vacuum cleaner	5 - 9	95%	Vacuum cleaner	5	95%
2	Steam cleaner	0.97 - 3.7	<5%	Handheld vacuum cleaner 3	1	< 5%
	New products :			Disappearing products:		
4	Sweeping and vacuum robot					

Market entry → Median residence time*: 7,9 years → Market exit

ProSUM

* The numbers for these products vary significantly per country


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4

0205 Personal Care

Appliance for hair beauty, curling/straightener device, dental care set, electrical hair removal equipment, electrical tooth brush, equipment for facial beauty, facial sauna, facial tanners and solaria, foot, face, skin and other massage appliances, hair clipper, hair dryer, hand dryer, irrigator, manicure and pedicure appliance, weighing scale, shavers and trimmers

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	Electric toothbrush	0.10 - 0.30	15%	Hairdryer	1	20%
2	Hairdryer	0.40 - 0.90	10%	Massage appliance	2	10%
3				Hair straightner and curl device	0	10%
	New products :			Disappearing products:		

Market entry → Median residence time*: 7,7 years → Market exit

ProSUM

* The numbers for these products vary significantly per country


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0301 Small IT

(Pocket) calculators, computer accessories (speakers, modems, etc.), docking station, external storage devices (external hard disk, external floppy drive, USB), external optical drives, external power supply and adapters, headsets with microphone (USB), keyboards, laser pointer, modem, mouse, router, webcam

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	Small IT products (general)**	0.20 – 0.68	100%	CD, DVD and other drives	3	60%
2				Mouse, keyboard, headsets, microphones, etc	1	35%
3				Calculators	0.4	< 5%
	New products :			**Disappearing products:**		
4	– Next gen fiber/dsl routers			- CD and DVD drives		
5	– 4G router					
6	– Wireless charging station					

Market entry — Median residence time*: 6 years — Market exit

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6 

* The numbers for these products vary significantly per country
** No further detailing available

0302 Desktop PCs

Desktop personal computers (excl. monitor, accessories), minitel

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	Desktop PC's	1.5 – 6.0	100%	Desktop PC's	9	95%
2				Minitel	4	< 5%
	New products :			**Disappearing products:**		
3	– All-in-One (AIO)			Minitel		

Market entry — Median residence time*: 8,5 years — Market exit



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2


3

* The numbers for these products vary significantly per country

0303 Laptops and tablets

Chart table, laptops, notebooks, other laptops, palmtops, tablets

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	Laptops	2.0 – 2.8	80%***	Laptops	2	95%**
2	Tablets	0.4 – 0.7	20%***	Chart table	2	< 5% **
	New products :			**Disappearing products:**		
				- Netbooks		

Market entry — Median residence time*: 7,4 years — Market exit


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2


3


4

* The numbers for these products vary significantly per country
** Numbers in red are estimated
*** Very time dependent

0304 Printers

Electronic typewriter, fax machine, label printer, Multifunctional, photo printer, printer /scanner, printers, scanners

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	Printers, scanners (all types)	1.3 – 3.0	90%**	Printer (except exclusively photo printer)	7	50%
				Scanner and printer Scanner	5	40%
2				Fax machine	4	10%

	New products :	Disappearing products:
3 4	– Hand-held 3D printers – 3D printer – Portable photo printers	- Fax

Market entry

Median residence time*: 7,2 years

Market exit

* The numbers for these products vary significantly per country

** Numbers in red are estimated


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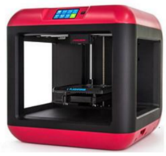
3



4

0305 Telecom

Answering machine, baby phone, call center, cordless phones, fixed telephone with or without wire, interphone, other household telecom, telephones (fixed), walkie-talkie

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	All telephones and small communication devices	0.4 – 1.0	90%**	Fixed telephone with or without wire	1	90%
2				Answering machine	1	5%
3				Intercom	1	< 5%

New products :	Disappearing products:

Market entry

Median residence time*: 5,6 years

Market exit

* The numbers for these products vary significantly per country

** Numbers in red are estimated


1

2


3

4

0306 Mobile Phones

Mobile phones, other mobile phone devices (pagers), smartphones

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight) *
1	All mobile phones and smartphones	0.1- 0.2	100%	Mobile phones	0.1	90%
2				Personal assistant, PDA	0.3	10%

	New products :	Disappearing products:
4	– Smartphone accessories	– Analog mobile phones – First generations mobile phones – Pagers 3

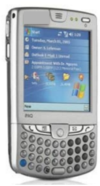
Market entry

Median residence time*: 4,4 years

Market exit

* The numbers for these products vary significantly per country

1



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0307 Professional IT

Professional multifunctional (fax, print, scan, copy, etc.), copiers, plotters and blueprinting, servers and workstations, overhead projectors and beamers, other professional and network equipment

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	All professional IT	3 - 90	100%	Photocopier	23	50%
2				Server	20	10%
3				Paper shredder	3	10%
	New products :			Disappearing products:		
4				– Fax		

Market entry → Median residence time*: 5 years → Market exit

* The numbers for these products vary significantly per country


1


2


3

0308 Cathode Ray Tube Monitors

CRT Monitors, parts of CRT monitors

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	Nil			CRT Monitors	16	100%
	New products :			Disappearing products:		
				– CRT Monitors		

Market entry → Median residence time*: X years (not placed on market anymore) → Market exit

* The numbers for these products vary significantly per country
** Numbers in red are estimated


1


2


3


4

0309 Flat Display Panel Monitors

LCD monitors, LED monitors, small flat screens

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	LCD Monitor	1.7 - 6.0	95%**	LCD Monitor	1.7 - 6.0	95%**
2				Digital photo frame < 7"	1	5*
	New products :			Disappearing products:		

Market entry → Median residence time*: 9.7 years → Market exit

* The numbers for these products vary significantly per country
** Numbers in red are estimated


1


2


3

0401 Small Consumer Electronics

Adapters and power supply consumer electronics, charger for primary and secondary batteries, headphones, headset (audio, tv, hifi), microphones, other small consumer electronics, remote control

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	Headphones	0.01 - 0.32	55%	Various chargers	0.3	80%
2	Various chargers	0.01 - 0.92	25%	Remote controls	0.1	10%
4	Microphone	0.03 - 0.97	10%	Chargers 3	0.8	10%
	New products :			Disappearing products:		
5 6	– Universal remote control – Portable battery pack					

Market entry → Median residence time*: 7 years → Market exit

ProSUM

* The numbers for these products vary significantly per country


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6

5

0402 Portable Audio & Video

Clock radio, e-readers, external CD DVD burner, karaoke machine, mp3 and mp4 players, navigation systems (portable), other portable audio, portable CD, MD, mp3, audio-video, player, hard disk, radio alarm clock with CD, portable radio, tape, speakers (portable), voice recorder

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	Radio	0.01 - 3.0	35%	Radio set, portable radio, tape and CD player, portable radio set	2	90%
2	Portable stereo	0.01 - 3.8	30%	Tape recorder, voice recorder	3	10%
3	Clockradio	0.15 – 0.8	25%			
	New products :			Disappearing products:		
				MP3 player 4		

Market entry → Median residence time*: 7,5 years → Market exit

ProSUM

* The numbers for these products vary significantly per country


1


2

3

4

0403 Radio, Hi-Fi, Music Instruments

Amplifier home cinema, amplifier, car stereo, mini-midi and micro sets, mixing panel, other audio components, other audio video accessories, receiver, records player, sound mixing boards, stereo, micro mini (home audio systems, all integrated elements), Tuner

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	Mini-midi and micro sets	2 - 9	25%	Mini-midi and micro sets	6	50%
2	Receiver	2 - 11	20%	Record player	5	15%
3	Amplifier	4 - 17	15%	Amplifier, receivers	5	15%
	New products :			Disappearing products:		

Market entry → Median residence time*: 8,5 years → Market exit

ProSUM

* The numbers for these products vary significantly per country


1

2

3

4

5


0404 Video

Antenna equipment, Blue-ray players and recorders, decoders and satellite receivers, DVD players and recorders, live box, professional consumer electronic equipment, set top box, TNT receiver, transcoder, TV antenna (except satellite dish and outdoor antenna), VCR players, video recorder

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	DVD player, recorders	0.12 - 7.9	40%	Video recorders	4	65%
2	Blu-Ray	0.76 - 7.0	25%	Decoders, cable and satellite receivers	1	30%
3	Decoders, cable and satellite receivers	0.68 - 2.37	20%	TV antenna (except satellite dish)	1	5%
	New products :			Disappearing products:		
				Betamax Video recorders		

Market entry

Median residence time*: 7,1 years

Market exit

vary significantly per country


1

2

3

4

* The numbers for these products vary significantly per country

0405 Speakers

Loudspeakers, multimedia speakers, speakers (individual), speakers (set)

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	Loudspeakers	0.01 - 12.8	70%	Loudspeaker, boxes	3	95%
2	Multimedia speakers	0.56 - 6.6	30%	Multimedia speakers	0,5	< 5 %
	New products :			Disappearing products:		
3	– Wireless audio streaming					

Market entry

Median residence time*: 8,4 years

Market exit


1

2

4

* The numbers for these products vary significantly per country

0406 Cameras

Cameras, camera zoom lens, digital still camera (photo), video camera (incl. photo function)

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	Digital cameras	0.11 - 0.78	90%	Video camera, digital camera	1	50%
	Camcorder	0.01 - 1.16	5%	Camera	0.3	45%
3	Video camera	0.19 - 1.2	<5%	Camera zoom lens	0.4	< 5%
	New products :			Disappearing products:		
	– 3D camera – 4K video camera			- Single-use cameras	6	

Market entry

Median residence time*: 6 years

Market exit


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3

4

5

6

* The numbers for these products vary significantly per country

0407 Cathode Ray Tube TVs

CRT TV's (incl. combi DVD, VCR), surveilance monitor CRT

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	Nil			CRT TV's	25	100%
	New products :			Disappearing products:		
				Cathode Ray tubes TVs		

Market entry — Median residence time*: X years (not placed on market anymore) — Market exit

* The numbers for these products vary significantly per country

1

0408 Flat Display Panel TVs

LCD TV's, LED TV's, Plasma TV's

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	LED TV***	7 - 16	55%	LCD TV's	16	95%
	LCD TV***	7 - 17	35%	Portable TV	3	< 5%
	Plasma TV**	14 - 29	<5%			
	New products :			Disappearing products:		
2 3	– Flexible Screens – QLED Screens – OLED Screens – 3D Display – UHD 4K TV			- Plasma TV's		

Market entry — Median residence time*: 9,4 years — Market exit

* The numbers for these products vary significantly per country
** Numbers in red are estimated
*** Very time dependent


1

2

3

0501 Small Lighting Equipment

Christmas lights and light strings (non-LED), Infrared lamp, insect killer, light mirror, other lamps (insects, tanning), pocket lamps

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	Christmas lights	0.01 - 1.5	75%	Insects electric lamp	0.90	75%
2	Flashlight	0.01 - 0.34	20%	Light mirror	3.47	20%
3	Insects electric lamp	0.5 - 0.9	<1%	Infrared lamp	0.98	<5%
	New products :			Disappearing products:		

Market entry — Median residence time*: 9 years — Market exit

* The numbers for these products vary significantly per country

1

2

3

0502 Compact Fluorescent Lamps

CFL lamps (integrated, household appliances), CFL lamps (non-integrated, professional), energy-saving lamp (screw/threaded fitting) CFL-I, energy-saving lamp (plug-in) CFL-ni

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected		Average Weight (kg/unit)	% Total share (weight)*
1	Compact fluorescent lamps (CFLs)	0.07 - 1.2	100%	Energy-saving lamp (screw/threaded fitting) CFL-i	2	0.09	50%
				Energy-saving lamp (plug-in) CFL-ni	3	0.07	50%
	New products :			Disappearing products:			

Market entry

Median residence time*: 6,9 years

Market exit

1

2

3

* The numbers for these products vary significantly per country

** Numbers in red are estimated

0503 Straight Tube Fluorescent Lamps

Fluorescent tubes, llight therapy device, solar lamp, straight fluorescent household, straight fluorescent B2C, tanning lamp, UV facial lamp

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	All straight tube fluor-escent lamps	0.06 - 0.18	100%	All straight tube fluorescent lamps	0.13	90%
2				Light therapy device	2.29	<5%
3				Fluorescent tubes (without product)	0.34	<5%
	New products :			Disappearing products:		

Market entry

Median residence time*: 5 years

Market exit

1

2

3

* The numbers for these products vary significantly per country

0504 Special Lamps

High pressure sodium, low pressure sodium, metal halide lamps, high pressure mercury

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	Metal halide lamps***	0.04 - 0.17	95%	All sodium/ metal halide/ high pressure mercury lamps ***	0.19	100%
2	High pressure sodium lamps ***	0.06 - 0.26	5%			
3	Low pressure sodium lamps***	0.01 - 0.31	<1%			
	New products :			Disappearing products:		

Market entry

Median residence time*: 6 years

Market exit

1

2

3

* The numbers for these products vary significantly per country

** Numbers in red are estimated

*** These numbers vary significantly per year

0505 LED Lamps

Retrofit LED lamps, LED inc. household luminaire, LED strings, LED halogen replacement

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	(Retrofit) LED lamps	0.01 - 1.4	95%	Led lamp (plug-in)	0.07	50%
2	LED strings	0.01 - 0.5	5%	Led lamp (screw/threaded fitting)	0.10	50%

New products :

3 – Gallium-nitride-on-silicon (GaN-on-Si) LEDs
– Smart LED lights
4 – Organic Light-emitting diodes (OLEDs)
– LED lamp (Zinc Selenide (ZnSe) LEDs)

Disappearing products:

Market entry

Median residence time*: 8 years

Market exit

* The numbers for these products vary significantly per country

** Numbers in red are estimated

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3

4

0506 Household Luminaires

Domestic lighting, extension cord, fitting a plurality of lights, fixture with a single point of light, household luminaires accessories, household luminaires, light line, light switch, network switch (switch), outlet, power strip, transformer for neon

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	Luminaire for a single lamp	0.01 - 4.0	65%	Household Luminaires	1.5	90%
	Luminaire for multiple lamps	1.3 - 4.2	35%	Extension lead, cord, power strip, outlet	0.5	5%
	Light line	0.30 - 1.7	<5%			

New products :

Disappearing products:

Market entry

Median residence time*: 11 years

Market exit

* The numbers for these products vary significantly per country

1

2

0507 Professional Luminaires

Professional LED luminaires, professional luminaires, professional lighting (neon support, disco lighting ...)

POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
Inside armature gas discharge	1.6 – 3.0	70%	Outside armature gas discharge	6	60%
Inside armature LED	0.4 – 1.8	15%	Inside armature gas discharge	6	40%
Outside armature gas discharge	1.7 – 3.1	10%			

New products :

Disappearing products:

Market entry

Median residence time*: 10 years

Market exit

* The numbers for these products vary significantly per country

0601 Household Tools

Block anti lightning housing, charger for car batteries, chipping hammer, heat gun, detacher, ripper, drill, file, grinder, perforator, sander, plane, saw, biscuit joiner, cleaning, drills, edger mower, trimmer mower, chainsaw, leaf blower, electric stapler office, electric nail stapler, electrical tile cutter, electrical toilet macerator, fountain with pump, generator, glue applicator, grass and hedges, grinders, high-pressure cleaner, machine polishing / polish (shoes), mower, other handheld tools, power supplies and adapters, robotic pool cleaner, sanders, saws, slicer, small portable electrical tool (electrical screwdriver), snow machine, bubble or smoke, soldering/welding iron and station, spraying, liquids, steam cleaner, tool sharpener, ultrasonic transmitter for animals , water filtering and pumps, waxing/polishing machine, welding and soldering.

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1, 2	Drills, grinders, sanders, saws, etc.	0.01 - 4.8	50%	Drills, grinders, sanders, saws, etc.	2	20%
3, 4	Lawn Mower, edge trimmer, leaf blower	1 - 20	20%	Lawn Mower, edge trimmer, leaf blower	11	15%
	High-pressure cleaner, pumps	7.7 - 21	15%	High-pressure cleaner, pumps	9	10%
	New products :			Disappearing products:		

Market entry

Median residence time*: 12,3 years

Market exit

* The numbers for these products vary significantly per country

1 

2 

3 

4 

0602 Professional Tools

Car washer, compressor, gas cylinder, professional cleaning, professional compressors, professional drills, professional paint, mixing fluids, professional power and air supply, professional sanders and grinders, professional saws

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	Compressors	20 - 45	45%	Compressor	7	80%
2	Professional table sawing machines	10 - 41	15%	Car washer	36	10%
	Scrubbers	6 - 250	10%	Generator	28	10%
	New products :			Disappearing products:		

Market entry

Median residence time*: 13 years

Market exit

* The numbers for these products vary significantly per country

1

2

3 

4 

0701 Toys

Electric model trains, small music toys, small toys, vehicle toys, car racing sets, biking computers

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	All small toys	0.01 - 2.30	100%			
	New products :			Disappearing products:		
2	– Drones					

Market entry

Median residence time*: 4 years

Market exit

* The numbers for these products vary significantly per country

1

2

0702 Game Consoles

Game consoles (portable), game consoles (TV, monitor connected), games (cards), games consoles accessories, professional game screen, videogames

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	All game consoles	0.01 - 2.3	100%	All game consoles	2.3	100%

New products :	Disappearing products:
– Augmented reality headset 2 – VR headsets – Next-gen gaming consoles 3 – Gaming accessories	

Market entry — Median residence time*: **3,4** years — Market exit

* The numbers for these products vary significantly per country

1 

2 

3 

0703 Leisure

Bicycle trainer, e-bikes, large music instruments, other exercise equipment, sport/leisure appliance, sunbeds (excl. Face tanners), stair lifts, scoot mobiles

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	E-bikes*	18 - 30	35%	Scoot-mobile (open and closed)	58 - 97	40%
2 3	Scoot mobile/ electric wheel chairs, lifts	14 - 96	30%	Electric wheelchair	86 - 144	20%
4	Cross-trainers	54 - 76	15%	Cardiology equipment (AED)	0.01 - 12	10%

New products :	Disappearing products:
6 – Electric skateboard/scooter – Hover board – Segway	

Market entry — Median residence time*: **10** years — Market exit

* The numbers for these products vary significantly per country

** Numbers in red are estimated

1 

2 

3 

4 

5 

6 

0801 Household Medical

Balneotherapy appliance, breast pump, centrifuge (lab / jewelry), dental electric cleaner, device for electric muscle stimulation, electrolysis unit, large medical, small medical, ultrasonic cleaner, thermometer

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	Blood pressure monitors	0.1 – 0.8	20%	All household medical	0.1 - 6	100%
2	Thermometers	0.01 – 0.33	20%			
3	Hearing aid	0.01 – 0.21	15%			

New products :	Disappearing products:
– Smart prosthetics	

Market entry — Median residence time*: **11** years — Market exit

* The numbers for these products vary significantly per country

1 

2 

3 

0802 Professional Medical

Professional dental equipment, large medical and dental electronic appliances, other hospital equipment, stair lift

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	Hospital equipment	0.01 - 150	75%	Hospital equipment	15	75%
2	Dental equipment	0.01 - 150	20%	Dental equipment	15	25%
	New products :			Disappearing products:		
3	- 4D ultrasound machine					

Market entry → Median residence time*: 12 years → Market exit



1 1


2 3

* The numbers for these products vary significantly per country

** Numbers in red are estimated

0901 Household Monitoring & Control

Burglary and robbery panel, clock thermostat, evacuation panel, fire panel, flow meter, garage equipment, gas detector, heat detector, ionization smoke detector, motion UV detector, other small monitoring, reader access, smoke / fire detectors, spanner

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
	Various household monitoring	0.01–0.90	30%	Electrical installation elements on electric meter	2.08	35%
1	(Smoke) detectors	0.04–0.36	15%	Measuring, controlling and monitoring equipment	1.05	25%
2	Thermostats	0.04–0.55	10%			
	New products :			Disappearing products:		
	- Sensor controlled devices					

Market entry → Median residence time*: 5 years → Market exit



1 2

* The numbers for these products vary significantly per country

0902 Professional Monitoring & Control

Electronic tag, negatoscope, professional control measuring element, professional monitoring, professional transformer (high voltage type)

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
	Control Unit (security)	0.01 - 37	55%	1 All Professional monitoring and control	5	100%
2	Surveillance (alarm panels)	0.01 – 6.5	25%			
	New products :			Disappearing products:		

Market entry → Median residence time*: 9 years → Market exit



1


2


* The numbers for these products vary significantly per country

1001 Non Cooled Dispensers

Cash register, hot drink vending machines, money authenticator, professional dispenser's non-cooled, food, terminal / card reader / time clock

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	Dispensers	7 - 250	95%	All dispensers and cash registers 2	4-60	100%
	Other vending machines	0.01 - 70	<5%			
	New products :			Disappearing products:		
3 4	– Retail assistant – Personal robots					

Market entry — Median residence time*: 8 years — Market exit

* The numbers for these products vary significantly per country

1


2


3


4


1002 Dispensers - Cooled

Commercial refrigeration: Other, Professional dispensers cooled food, Wholesale Vending Machines

	POM	Average Weight (kg/unit)	% Total share (weight)	Collected	Average Weight (kg/unit)	% Total share (weight)*
1	Automatic cooling / freezing	19.6 - 250	100%	Commercial refrigeration: Other	30	95%
				Wholesale Vending Machines 2	10	5%
	New products :			Disappearing products:		

Market entry — Median residence time*: 12 years — Market exit

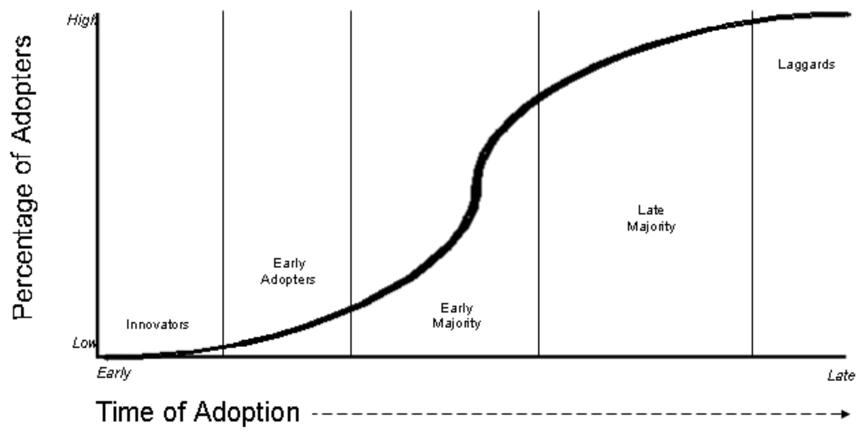
* The numbers for these products vary significantly per country

1

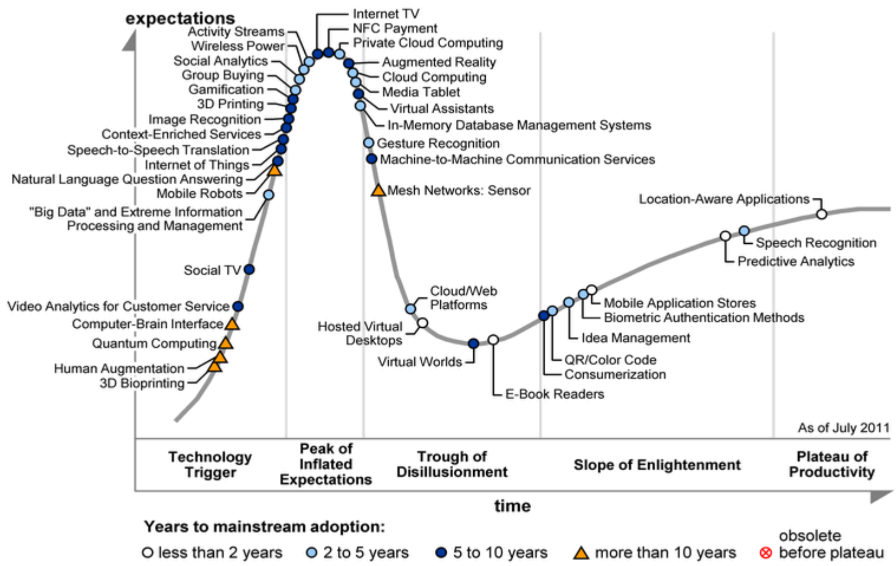

2

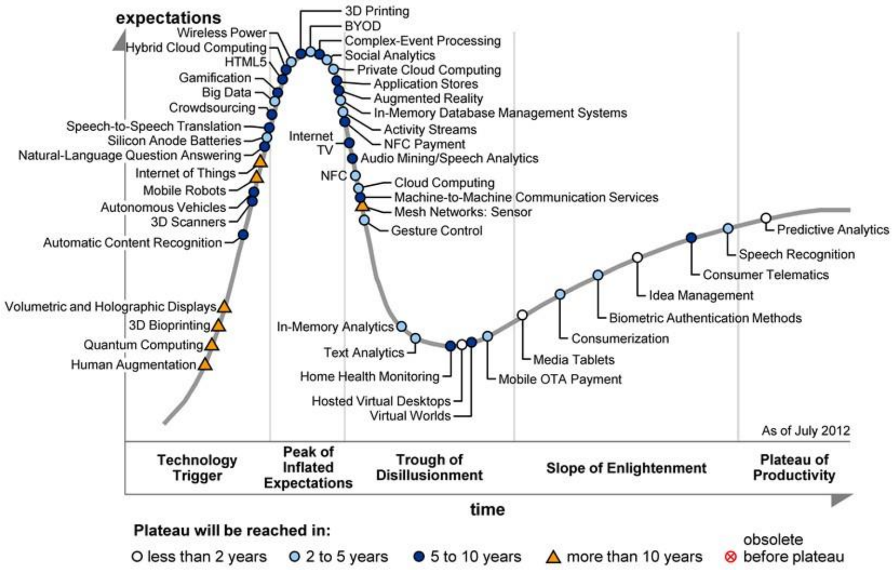

7.2 Annex 2 Hype Cycles and S-curves for EEE

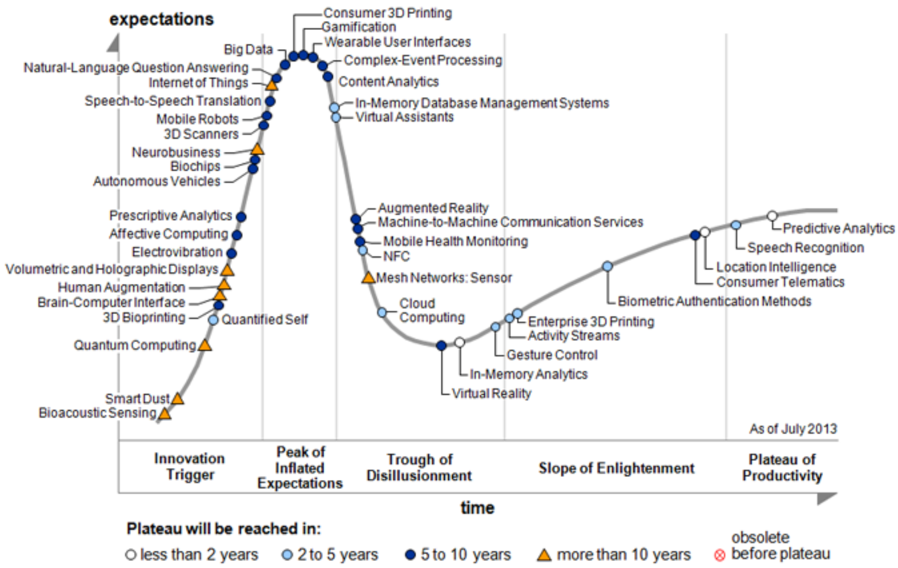
S-curve reflecting the time of adoption is given.

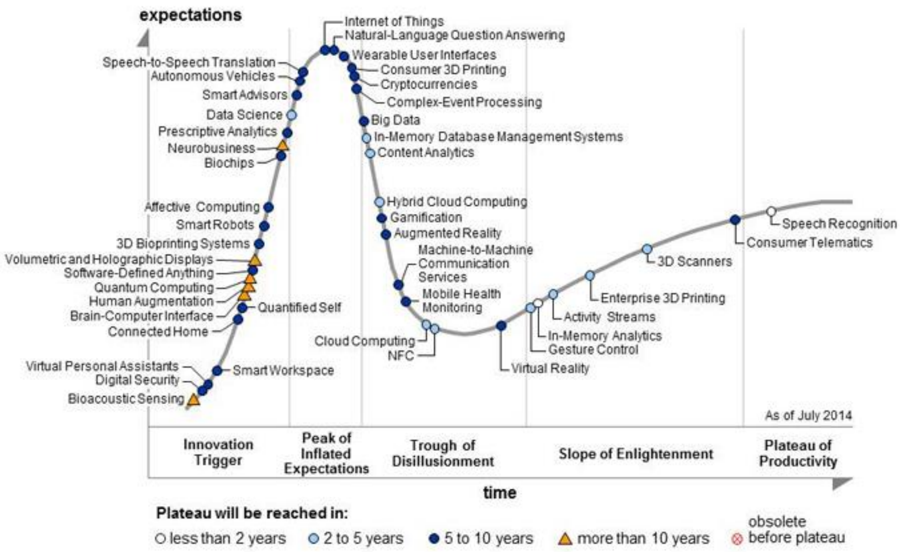


Below, the consecutive hype cycles for new products are presented for the period 2011 – 2016.




expectations
3D Printing
BYOD
Complex-Event Processing
Social Analytics
Private Cloud Computing
Application Stores
Augmented Reality
In-Memory Database Management Systems
Activity Streams
NFC Payment
Audio Mining/Speech Analytics
Cloud Computing
Machine-to-Machine Communication Services
Mesh Networks: Sensor
Gesture Control
Wireless Power
Hybrid Cloud Computing
HTML5
Gamification
Big Data
Crowdsourcing
Speech-to-Speech Translation
Silicon Anode Batteries
Natural-Language Question Answering
Internet of Things
Mobile Robots
Autonomous Vehicles
3D Scanners
Automatic Content Recognition
Internet TV
NFC
Volumetric and Holographic Displays
3D Bioprinting
Quantum Computing
Human Augmentation
In-Memory Analytics
Text Analytics
Home Health Monitoring
Hosted Virtual Desktops
Virtual Worlds
Media Tablets
Mobile OTA Payment
Consumerization
Biometric Authentication Methods
Idea Management
Consumer Telematics
Speech Recognition
Predictive Analytics
As of July 2012
Technology Trigger
Peak of Inflated Expectations
Trough of Disillusionment
Slope of Enlightenment
Plateau of Productivity
time
Plateau will be reached in:
less than 2 years
2 to 5 years
5 to 10 years
more than 10 years
obsolete before plateau


expectations
Consumer 3D Printing
Gamification
Wearable User Interfaces
Complex-Event Processing
Content Analytics
In-Memory Database Management Systems
Virtual Assistants
Big Data
Natural-Language Question Answering
Internet of Things
Speech-to-Speech Translation
Mobile Robots
3D Scanners
Neurobusiness
Biochips
Autonomous Vehicles
Prescriptive Analytics
Affective Computing
Electrovibration
Volumetric and Holographic Displays
Human Augmentation
Brain-Computer Interface
3D Bioprinting
Quantified Self
Quantum Computing
Smart Dust
Bioacoustic Sensing
Augmented Reality
Machine-to-Machine Communication Services
Mobile Health Monitoring
NFC
Mesh Networks: Sensor
Cloud Computing
Enterprise 3D Printing
Activity Streams
Gesture Control
In-Memory Analytics
Virtual Reality
Biometric Authentication Methods
Location Intelligence
Consumer Telematics
Speech Recognition
Predictive Analytics
As of July 2013
Innovation Trigger
Peak of Inflated Expectations
Trough of Disillusionment
Slope of Enlightenment
Plateau of Productivity
time
Plateau will be reached in:
less than 2 years
2 to 5 years
5 to 10 years
more than 10 years
obsolete before plateau


expectations
Internet of Things
Natural-Language Question Answering
Wearable User Interfaces
Consumer 3D Printing
Cryptocurrencies
Complex-Event Processing
Big Data
In-Memory Database Management Systems
Content Analytics
Speech-to-Speech Translation
Autonomous Vehicles
Smart Advisors
Data Science
Prescriptive Analytics
Neurobusiness
Biochips
Affective Computing
Smart Robots
3D Bioprinting Systems
Volumetric and Holographic Displays
Software-Defined Anything
Quantum Computing
Human Augmentation
Brain-Computer Interface
Connected Home
Quantified Self
Virtual Personal Assistants
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Smart Workspace
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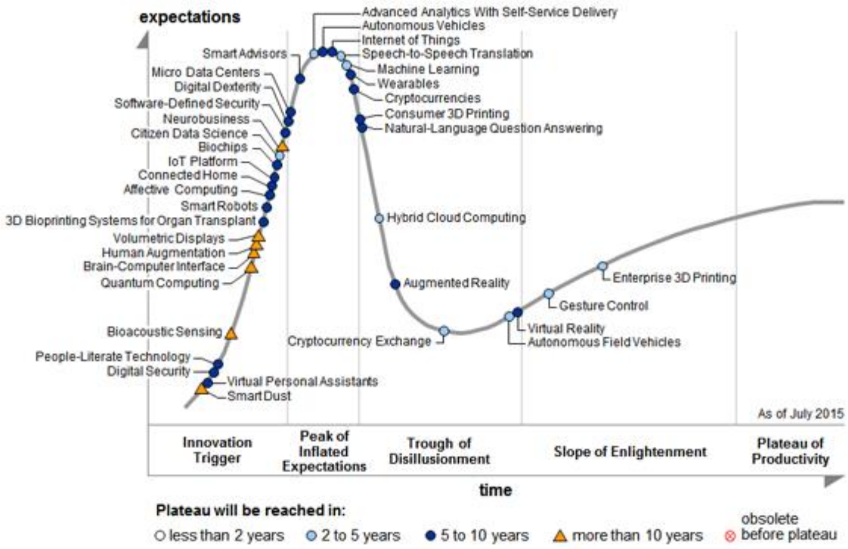
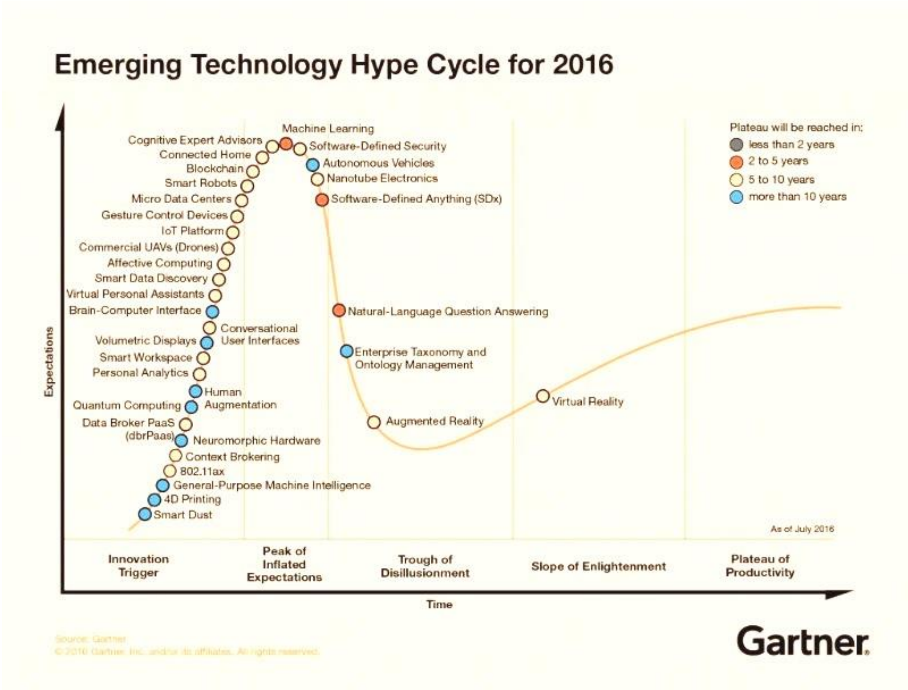
Mobile Health Monitoring
Cloud Computing
NFC
Virtual Reality
Enterprise 3D Printing
Activity Streams
In-Memory Analytics
Gesture Control
3D Scanners
Consumer Telematics
Speech Recognition
As of July 2014
Innovation Trigger
Peak of Inflated Expectations
Trough of Disillusionment
Slope of Enlightenment
Plateau of Productivity
time
Plateau will be reached in:
less than 2 years
2 to 5 years
5 to 10 years
more than 10 years
obsolete before plateau


expectations
Advanced Analytics With Self-Service Delivery
Autonomous Vehicles
Internet of Things
Speech-to-Speech Translation
Machine Learning
Wearables
Cryptocurrencies
Consumer 3D Printing
Natural-Language Question Answering
Smart Advisors
Micro Data Centers
Digital Dexterity
Software-Defined Security
Neurobusiness
Citizen Data Science
Biochips
IoT Platform
Connected Home
Affective Computing
Smart Robots
3D Bioprinting Systems for Organ Transplant
Volumetric Displays
Human Augmentation
Brain-Computer Interface
Quantum Computing
Bioacoustic Sensing
People-Literate Technology
Digital Security
Virtual Personal Assistants
Smart Dust
Hybrid Cloud Computing
Augmented Reality
Cryptocurrency Exchange
Enterprise 3D Printing
Gesture Control
Virtual Reality
Autonomous Field Vehicles
As of July 2015
Innovation Trigger
Peak of Inflated Expectations
Trough of Disillusionment
Slope of Enlightenment
Plateau of Productivity
time
Plateau will be reached in:
less than 2 years
2 to 5 years
5 to 10 years
more than 10 years
obsolete before plateau


Emerging Technology Hype Cycle for 2016
Expectations
Machine Learning
Cognitive Expert Advisors
Software-Defined Security
Connected Home
Blockchain
Autonomous Vehicles
Smart Robots
Nanotube Electronics
Micro Data Centers
Software-Defined Anything (SDx)
Gesture Control Devices
IoT Platform
Commercial UAVs (Drones)
Affective Computing
Smart Data Discovery
Virtual Personal Assistants
Brain-Computer Interface
Natural-Language Question Answering
Conversational User Interfaces
Volumetric Displays
Enterprise Taxonomy and Ontology Management
Smart Workspace
Personal Analytics
Human Augmentation
Quantum Computing
Virtual Reality
Data Broker PaaS (dbrPaas)
Augmented Reality
Neuromorphic Hardware
Context Brokering
802.11ax
General-Purpose Machine Intelligence
4D Printing
Smart Dust
Plateau will be reached in:
less than 2 years
2 to 5 years
5 to 10 years
more than 10 years
As of July 2016
Innovation Trigger
Peak of Inflated Expectations
Trough of Disillusionment
Slope of Enlightenment
Plateau of Productivity
Time
Gartner

7.3 Annex 3 Component Manufacturer Questionnaire

		e-c 2010	e-c 2015	e-c 2020	e-m		e-c 2010	e-c 2015	e-c 2020	e-m		e-c 2010	e-c 2015	e-c 2020	e-m		e-c 2010	e-c 2015	e-c 2020	e-m	
Component (Class)	**CRM**	**Content (mg)**	**Content (mg)**	**Content (mg)**	**Contained in (homogene-ous material)**	**CRM**	**Content (mg)**	**Content (mg)**	**Content (mg)**	**Contained in (homogene-ous material)**	**CRM**	**Content (mg)**	**Content (mg)**	**Content (mg)**	**Contained in (homogene-ous material)**	**CRM**	**Content (mg)**	**Content (mg)**	**Content (mg)**	**Contained in (homogene-ous material)**	**Comments**
	Precious Metals					**Metals of Rare Earths (heavy)**					**Metals of Rare Earths (light)**					**Other Materials**					
	Gold					Dysprosium					Cer					Antimony					
	Silver					Erbium					Europium					Beryllium					
	Palladium					Gadolinium					Lanthanum					Borates					
	Platinum					Holmium					Neodymium					Chromium					
Please specify the component or component class	Rhodium					Lutetium					Preaseodymium					Cobalt					
	Ruthenium					Terbium					Samarium					Gallium					
	Osmium					Thulium					Scandium					Germanium					
	Iridium					Ytterbium										Indium					
						Yttrium										Magnesium					
																Niobium					
																Silicon metal					
																Wolfram					
Component (Class)	**CRM**	**Content (mg)**	**Content (mg)**	**Content (mg)**	**Contained in (homogene-ous material)**	**CRM**	**Content (mg)**	**Content (mg)**	**Content (mg)**	**Contained in (homogene-ous material)**	**CRM**	**Content (mg)**	**Content (mg)**	**Content (mg)**	**Contained in (homogene-ous material)**	**CRM**	**Content (mg)**	**Content (mg)**	**Content (mg)**	**Contained in (homogene-ous material)**	**Comments**
	Precious Metals					**Metals of Rare Earths (heavy)**					**Metals of Rare Earths (light)**					**Other Materials**					
	Gold					Dysprosium					Cer					Antimony					
	Silver					Erbium					Europium					Beryllium					
	Palladium					Gadolinium					Lanthanum					Borates					
	Platinum					Holmium					Neodymium					Chromium					
Please specify the component or component class	Rhodium					Lutetium					Preaseodymium					Cobalt					
	Ruthenium					Terbium					Samarium					Gallium					
	Osmium					Thulium					Scandium					Germanium					
	Iridium					Ytterbium										Indium					
						Yttrium										Magnesium					
																Niobium					
																Silicon metal					
																Wolfram					
Component (Class)	**CRM**	**Content (mg)**	**Content (mg)**	**Content (mg)**	**Contained in (homogene-ous material)**	**CRM**	**Content (mg)**	**Content (mg)**	**Content (mg)**	**Contained in (homogene-ous material)**	**CRM**	**Content (mg)**	**Content (mg)**	**Content (mg)**	**Contained in (homogene-ous material)**	**CRM**	**Content (mg)**	**Content (mg)**	**Content (mg)**	**Contained in (homogene-ous material)**	**Comments**
	Precious Metals					**Metals of Rare Earths (heavy)**					**Metals of Rare Earths (light)**					**Other Materials**					
	Gold					Dysprosium					Cer					Antimony					
	Silver					Erbium					Europium					Beryllium					
	Palladium					Gadolinium					Lanthanum					Borates					
	Platinum					Holmium					Neodymium					Chromium					
Please specify the component or component class	Rhodium					Lutetium					Preaseodymium					Cobalt					
	Ruthenium					Terbium					Samarium					Gallium					
	Osmium					Thulium					Scandium					Germanium					
	Iridium					Ytterbium										Indium					
						Yttrium										Magnesium					
																Niobium					
																Silicon metal					
																Wolfram					