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Waste management potential of LED products with no lighting function and no technical relevant signaling function

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Preface

"Sustainable development, is development that meets the needs of the present without compromising the ability of future generation to meet their own needs."

As my generation, in central Europe has the benefit of not having to deal with primary needs of providing food and shelter, we are obliged to be concerned about future generation, so they can meet their needs in the same way as it is possible for us. Furthermore, our horizon has grown with in the same speed as globalization took over the whole planet. Hence, our behavior does not only affect our direct surrounding, moreover, every action we take has a global impact but many people are not aware of this fact. Our food gets shipped over the whole planet, just to make sure that everything is available at every time and everywhere, if you are able to afford it. Our cloths are sewed in developing countries under threating conditions, just to keep them as cheap as possible. Our everyday electronic devices consume more resources than ever. And in the end, everything gets obsolete and dumped anywhere around the planet. Sadly, everyone knows the price, but the value has been forgotten. For all these reasons, I chose my studies. It is in our responsibility, regarding the knowledge mankind gather and experience that was made, to act responsible and in a sound manner to provide a live worthy world for future generations.

Waste management therefore, is more than just "cleaning up". Waste management is an integral part of providing a sustainable growth for a sustainable future. Therefore, I am thankful to had the privilege of studying this subject.

I want to thank my family, especially my parents for providing me everything it needed to get to this point and never questioned my decisions. Moreover, I want to thank, the University of life science to teach critical and independent thinking. Especially I have to thank Professor Marion Huber-Humer for her professional input and to help with words and deeds. Also, I have to thank Professor Peter Schwarzbauer for his professional help with the survey.

In the end, I want to thank all my friends, without whom I could have finished my studies two years earlier, but with less fun and pleasure!

A. Abstract

As waste management has to react on new upcoming waste streams, the waste management potential of LED products, with no lighting function and no technical relevant signaling function was inquired. With an uprising LED market worldwide and the technical development, more and more everyday products get enlighten for no reason. The paper is based on a survey to measure the mass of the investigated products in Austrian households and to draw conclusions about the disposal behavior. Further on, four sample products have been dismantled and analyzed. In a next step, the hazardous potential is discussed. With detailed data of the products and the knowledge about the way of disposal, waste streams were calculated. The waste stream is of nearly no currently relevance as it is 0.49% of all collected WEEE in Austria in 2014. Still, LEDs have to be taken into account as the market is growing rapidly. LEDs have a hazardous potential due to the metals used. Moreover, with proper recycling technology LEDs have a high potential for urban mining, as the gold content is higher than in the average gold ore. In addition, gold and silver have the potential to cause resource shortages if the production does not change. There is a big lack in data for LED disposal, their hazardous potential and their end of life treatment. There was also no communication from producers, authorities and retailers. The survey acknowledged, that people still tend to use the residual waste for disposing small WEEE.

B. Kurzfassung

Da die Abfallwirtschaft frühzeitig auf aufkommende Abfallströme reagieren muss, untersucht diese Arbeit das abfallwirtschaftliche Potential von Led Produkten ohne Beleuchtungszweck und technisch relevanter Signalgebung. Durch einen immer schneller wachsenden, weltweiten LED-Markt und den technologischen Fortschritten, werden immer mehr Alltagsprodukte ohne jeglichen Grund mit Leuchtmitteln ausgestattet. Um diesen Abfallstrom darzustellen, wurde ein Umfrage durchgeführt. Durch diese konnte die Menge der gesuchten LED-Produkte sowie das Entsorgungsverhalten der Konsument bestimmt werden. Im Anschluss wurden vier repräsenative Produkte zerlegt und analysiert. Weiter wurde das Gefahrenpotential von LEDs, bezüglich der verwendeten Materialien bestimmt. Mit den gesammelten Daten wurde im Anschluss die Masse des Abfallstroms berechnet. Der durch die gesuchten Produkte entstehende Abfallstrom weist bezüglich seines Volumens momentan kaum abfallwirtschaftliche Relevanz auf, da es sich dabei um 0,49% der gesamt gesammelten Menge an WEEE in Österreich im Jahr 2014 handelt. Trotzdem müssen LEDs beachtet werden, da der Markt ein rasantes Wachstum erlebt und die untersuchte Produktgruppe nur eine Randnotiz davon ist. LEDs besitzen ein generelles Gefahrenpotential aufgrund der verwendeten Metalle aber auch ein hohes Urbanminingpotential, da sie durchschnittlich mehr Gold enthalten als Golderz. Jedoch fehlt die richtige Recyclingtechnologie. Generell haben Gold und Silber, sollte sich die Produktionsweise nicht ändern, das Potential zu Ressourcenengpässen zu führen. Weiter gibt es ein großes Defizit an wissenschaftlichen Daten zum Gefahrenpotential sowie zu Recycling und Entsorgungsverfahren von LEDs. Weiterführend gab es auch keine Kommunikation von Seiten der Hersteller, Dachverbände und Händlern. Die Umfrage bestätigte weiter, dass die Befragten noch immer dazu tendieren kleine Elektroaltgeräte im Haushalts Müll zu entsorgen.

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1. Introduction

In a globalized world, the technical growth and the availability of products increases faster and faster. New products enter the worldwide market every day and every day billions get obsolete. These products often end up at informal dumps or get disposed without any concerns of their hazardous and resource potential. For this reason, the industry as well as waste management must think in long terms. The industry is obliged to develop more sustainable and easier to handle after end of life products. As this is happening very slow, the waste management has to adapted. Possible new waste streams have to be detected in time and handled in the right way. This conforms with the precautionary principle, a guideline in the European environmental policy. It says, that even if there is not enough scientific evidence for a threat, security measures have to be taken to prevent possible future threats (BMLFUW, 2017a).

This paper deals with the research questions of a new possible waste stream caused by LED products with no lighting function and no technical relevant signaling function and its waste management potential in 2017 in Austria. The following sub questions will answer the research question. Are the investigated LED products of any quantitative relevance for the Austrian waste management in 2017? Is there a threat caused by the material composition of the investigated LED products in 2017? How to assess the disposal behavior for the investigated LED products in 2017 in Austria? How to assess the resource potential of the investigated LED products in 2017 in Austria?

As the technique of light emitting diodes (LED) made big progress, their environmental friendly image and their energy saving potential, let the market grow rapidly. In the European Union, the market volume grew from one billion euros in 2011 to nine billion euros in 2016 and is supposed to reach 14 billion euros in 2020 (Statista, 2017a). LEDs are used for general lighting, because of their long lifespan as well as for their low energy consumption. Furthermore, LEDs are used for display background lighting, due to the possibility of nano-scale production and their small design. But since the technique gets cheaper, more and more products get enlighten for barley no reason. These Products are for example, enlighten decoration, apparel, accessorize or toys. As these products are not covered in any statistic and/or scientific paper, this paper tries to evaluate their occurrence in Austrian households and their end of life destination to reveal their waste management relevance.

In the beginning a quick overview on the Austrian waste management system is given, with details on the separate collection scheme, the WEEE (waste electrical and electronic equipment) situation in Europe and Austria followed by a short excursion regarding drivers for waste management development. The paper continues, by providing information about the LED market, the technical background of LEDs and their possible environmental impact.

Chapter 5.1 deals with the survey, the empirical foundation of this paper. The mass of the investigated LED products is evaluated, as well as the disposal and consumer behavior. Hypothesis regarding relations between different levels of education or age and the amount of owned LED items as well as the disposal behavior are tested. The paper also takes a look at the influence of rural or urban lifestyles on separate waste collection.

In chapter 5.2 four selected products, for each product group are analyzed, regarding the used LED technique, the total mass of the product and the mass of the electronic component. By knowing, the specific LED type, calculations were made to figure out the metal content of each product caused by the used LEDs, the mass of the total waste stream, the mass of the electronic components generated in this waste stream, the mass for every single disposing opportunity and the metals reaching each of them.

2. Method

The evaluation of the waste management potential of LED products with no lighting function and no technical relevant signaling function, included two steps. In the first one a survey was implemented. In the second step, the investigated products were analyzed.

2.1 Method of the survey

As there was no data available regarding this topic, it was necessary to ascertain new primary data. In a first step a definition was made up to narrow down the investigated products. The products define as follows:

- It must have one operating LED
- It has to be a decoration, an accessorize, an apparel or a toy
- Its original function can be complied without LEDs
- It has no primary illumination function
- It does not replace any conventional non-LED lamp
- The LED does not give any information about the state of charge of this product
- The LED does not support the safety of the use.

The products, have been categorized in four different groups as they are decoration, accessorize, apparel and toys. This happened for different reasons. First it will help to calculate the quantity of WEEE generated by the consumption of these products as they use different amount of resources. Second, people are likely to dispose these goods in different ways, whereas all of them must be disposed as e-waste.

Further on, a survey was compiled. It contained 16 questions dealing with type and amount of the investigated products, the disposal behavior for them, the consumer behavior and demographical data. The setup, for the survey was done with help from Professor Schwarzbauer and a literature research (Field, 2009). The questions can be seen below.

- How many of the defined products do you have in your household?

For simplification, people had to answer this question within a range of numbers, as they were 1 to 3, 4 to 6, 7 to 9, 10 to 15, 16 to 20 and more than 20. With this method the handling time for the participant was reduced.

Question two to five asked for the quantity for each of the four different product groups kept in Austrian households.

- How many of these products are accessorize/ apparel/ decoration/ toys?

Again, people were asked within a range of numbers, as they were: no product at all, 1 to 3, 4 to 6, 7 to 9 and 10 or more.

Continuing with question 6 to 9 people had to answer questions regarding their disposal behavior for every product group.

- Where would you dispose accessorize/ apparel/ decoration/ toys?

People had to choose between residual waste, WEEE, plastic waste, passing on or selling it or they were free to fill in their own suggestion. For the product group of apparel, the option of plastic waste was replaced by old cloth collection.

Question 10 dealt with the place of retail:

- Where did you get the investigated product from?

Four answers were given: in an online shop, at a local retailer, as a gift and the opportunity to fill in another suggestion.

The survey asked for the approximated service life of the products in question 11.

- How long will you use the product after the purchase?

The sample had to choose between only once, 1 to 6 months, 7 to 12 months and over a year.

Question 12 asked for the sex of the participant and question 13 continued with the age, whereas people had to choose between different age groups, as they were under 18, 18 to 24, 25 to 29, 30 to 39, 40 to 49, 50 to 59 and 60 and older. Continuing with household size the answer options of single household, 2 to 4 persons and more than 4 persons were provided. Question 15 asked for the highest level of education, with the following answer options: compulsory school, apprenticeship, vocational middle school, grammar school, vocational high school, college and university. The last question,16, asked for the area of residence. People had to choose between urban and rural area.

The survey was launched at an online platform and spread as a paid Facebook advertisement to have a larger reach outside the information bubble of the author. Further the survey was linked to a lottery to gain more participants. The original survey can be seen in appendix 1.

To assess the survey Microsoft Excel was used. The data set was analyzed regarding descriptive statistic key figures, as they were mean, median and standard deviation. The statistic background knowledge was found in Filed (2009). Moreover, the following four hypotheses were tested:

- The number of investigated products in Austrian households decreases by an increasing level of education.
- The number of investigated products in Austrian households decreases as people get older.
- An increasing awareness for the right disposal behavior of LED products with an increasing level of education.
- A decreasing awareness for the right disposal behavior of LED products with increasing age.

Further on it has to be said, that all calculations have been done within a range of numbers. That means, for every outcome there is a minimum, a maximum and mean figure, as people answered the questions in a range of numbers. For example, if one sample said, she/ he has 1-3 products in her/ his household, there is the possibility, that she/ he owns 1,2 or 3 products. So, the minimum describes the outcome, if she/ he owns only 1 and the maximum if she/ he owns 3 products. The mean represents the middle of the group. For the answer option “more than 20” it was assumed to calculate with a maximum of 25 items. For “more than 10” calculations were made with a maximum of 15 products. If an outcome is only calculated with mean figures, it is highlighted.

2.2 Method of analyzing the sample products

Four sample products have been chosen to represent each of the four product groups. Next, the whole product got weighed with an accuracy of 1 gram. Further on, the products got dissembled. The electro technical parts got weighed with a scale of an accuracy of 0.01 gram. Next, one 5mm pin type LED got weighed. To categorize the LEDs, the illuminance was measured with a lux meter. The metering took place in darkness with a distance of 10cm. Knowing the distance between light source and sensor as well as the illuminance in lux it is possible to calculate the luminous intensity in candela with the formula: $I_{v(cd)} = E_{v(lx)} \times (d_{(m)})^2$ (Rapidtables, 2017). By knowing the luminous intensity and the color of the LED, the metal content for each sort of LED was taken out of a study by Lim et al. (2017). The study provides metal contents for each sort of LED. The data is given in mg/kg. With this data and knowing the weight of one LED, it was possible to calculate the metal content for a single LED. Knowing, the amount of LED products in every product group and the number of LEDs used in every product as well as the metal content, it was possible to calculate the approximated metal content for all LEDs used in the investigated products in Austrian households. With the following four formulas all calculations can be done.

- Metal content by LED [mg] $= \frac{metal\ content\ [\frac{mg}{kg}]}{1\ 000\ 000} \times 0{,}21$
- Metal content of all LEDs used $= metal\ content\ by\ LED\ \times LEDs\ per\ product\ \times amount\ of\ products\ in\ austrian\ households$
- Metal content by way of disposal $= metal\ contant\ per\ LED\ \times LEDs\ per\ product\ \times products\ per\ waste\ stream$
- Total mass per waste stream $= mass\ per\ product\ \times product\ per\ waste\ stream$

The relevant background data was gained through “Scopus”, the Boku-library and managed via “Mendely”.

3. The Austrian waste management system and upcoming waste streams.

Regarding to the Federal Ministry of Agriculture, Forestry, Environment and Water Management in Austrian (BMLFUW), the waste management is based on a sustainable development. Its legal foundation is the waste management law, (Abfallwirtschaftsgesetz or AWG) from 2002 and several amendments to adopt new targets or react to new circumstances. The main goal of the law is to protect humans and the environment. This goal should be reached through low emissions and an efficient utilization of resources (BMLFUW, 2015).

The implementation of this law happens on different levels. The constitutional law claims the jurisdiction of hazardous waste at federal level. Any other field has to be covered by state level, unless the federal level claims that topic for itself. To cover the topic of non-hazardous waste the federal level made use of its right “authority in case of need” and issued the AWG 2002. This law deals with the rights and duties of waste owners, waste treatment operators, waste collectors and collection and treatment facilities. Moreover, it legally regulates operation facilities, transboundary shipment and the collection of problematic material. Briefly, the AWG says that the communities have to organize a collection for problematic material (not e-waste) at least twice a year. Biological waste, must be (home)composted by the producer, collected by the community or a municipal collection point must be provided. Distributers of packaging, WEEE, automobiles and batteries must build up a collection and treatment network, which allows the consumer to dispose their goods for free. The distributors must treat these goods law-abiding. Producers of industrial or commercial waste, must take care of the waste on their own, following the law. The treatment has to be economical and ecological sustainable. Moreover, the operator of a collection and treatment services has to make sure, that the destination of the waste is clear and comprehensible. The treated or disposed good, must not pose a threat for humans and the environment (BMLFUW, 2015).

3.1 The separate collection scheme in Austria

The separate collection is the backbone of the Austrian success in waste management and unalterable for a sustainable recycling and disposal system. Moreover, to evaluate the waste management relevance of an upcoming waste stream, it is necessary to understand all possible ways of disposal to track down the end of life destination of the disposed good. Through this resource losses can be ascertained. Further, it partly explains why people still dispose their waste in the wrong way.

Starting with residual waste, every community is responsible for its collection. Most of the time a door to door collection is used with an interval from 52 to 13 times a year, depending on the structure of the area. In rural areas, a lower frequency is used than in urban areas. The responsibility for bulky waste is also by the communities. Normally the collection takes place at local recycling centers, or sometimes as a door to door collection. Biological waste is also in the hand of the communities and collected door to door, if the producer does not compost it himself. Continuing with paper, the responsibility is mixed up. As paper from households contains packaging as well as print work, the competence is by the distributor of the packing and the communities. To make the grade, private recyclers e.g. the ARA pay, a regional dependent fee per ton, but also get their share from the proceeds. The collection scheme is mixed, from door to door to municipal waste collection islands. Similar to the paper collection system, light packaging and metal packing is collected. Regarding household scrap, there is no specific legal framework, but for economic reasons it is collected as bulky waste by the community. Last but not least in the group of separate waste collection from households, there is the collection of problematic material. As mentioned bevor, the communities are obliged to offer a collection at least twice a year. Normally there are two different collection systems. On the one hand, there are municipal collection points, where people drop off the goods and on the other hand there are mobile collection points. Usually the collection facilities distinguish between 20 different sorts of problematic material. E-waste is one of these categories but could also be given back 1:1 when a new one is purchased at a retailer. But even, the collection system for WEEE is highly developed in Austria not all of the potential WEEE gets collected. This happens for several reasons. Large household appliances maybe disposed with bulky waste. Some consumers do not dispose their WEEE immediately but store them at home or appliances which still work may be sold or shipped abroad. Often WEEE gets lost, through informal collections.(BMLFUW, 2015)

Moreover, there is also a separate collection for commercial waste producers, but as it is of no importance for this study, it will not be mentioned further. If there is any interest, it can be looked up by “Die Bestandsaufnahme der Abfallwirtschaft in Österreich Statusbericht 2015”(BMLFUW, 2015).

In 2014, waste from private households was 8.2% of the total occurrence in Austria, which were 4.02 million tons. Table 1 shows the structure of household waste in 2014 regarding to the waste management review of the ministry from 2015.

Biological waste	29.5%
Paper and cardboard	18.1%
Plastic	8.1%
Glass	6.3%
Wood	7.6%
Metal	3.7%
Inert material	1.5%
Hygiene products	7%
Textiles	2.7%
WEEE	**2%**
Problematic material	0.6%
Mattress and carpets	0.8%

Other existing chemical substance	0.6%
Other waste material	11%

Table 1: fractions of household waste in mass percent (BMLFUW, 2015)

3.2 WEEE in Europe and Austria

WEEE (waste electrical and electronic equipment) is the fastest growing waste stream in the EU. The accrual rate is three times higher than for municipal waste (Dimitrakakis et al., 2009). Regarding to Eurostat (2017a) the annual growth is by 3-5%. Reasons for that, are the growing digitalization and decreasing life time of electronic products. For example, the life time of a CPU decreased from six years in 1997 to only two years in 2005 (Widmer et al., 2005). Hence that a separate collection is very important to minimize the loss of resources and the threat for the environment. For this reason, the EU implemented the regulation 2012/19/EU. Figure 1 shows a simplified process scheme of the EU WEEE directive. Since 2016, 45% of the mass of waste electrical and electronic equipment, that was distributed the last three years has to be collected and treated. In Austria around 20.6kg of electronic goods come on the market every year per person, which is mid-table in the European Union. Around 9 kilograms per person were collected in 2014, whereof nearly 40%, 3.57kg are small applications (Unger et al., 2017).

In total numbers, 3 483 352 tons of WEEE had been collected in 2015 in the EU, whereof 2 845 996 tons have been recycled or reused. In Austria 80 246 tons were collected and 65 090 tons have been treated for recycling. This means a recycling rate of 81% of the collected mass (Eurostat, 2017b). Regarding table 1 WEEE is 2% of the total mass of household waste in Austria.

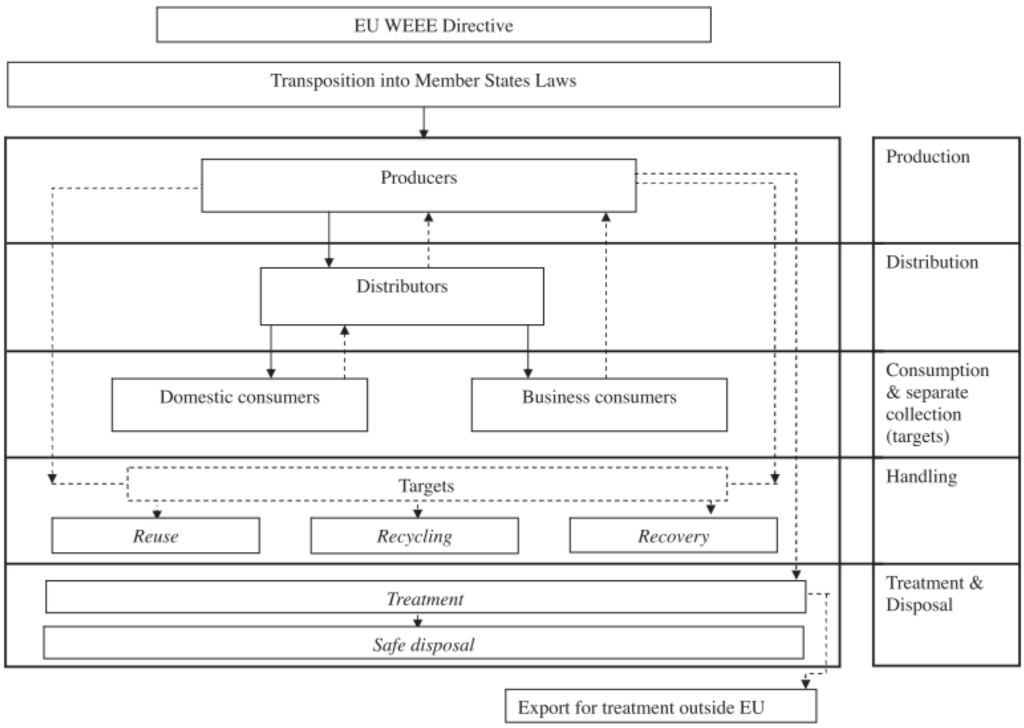

Figure 1: simplified scheme of the EU WEEE directive (Ongondo et al., 2011)

Treating WEEE is a very complex matter, as the product diversity is very high. Therefore, also the composition of materials is very divers. Most of the time different materials such as metals and plastic are found as composite, what makes it difficult to separate. Next to precious materials like gold, silver, copper, aluminium, rare earths and plastic there are also hazardous substances. For example, capacitors, batteries and brominated flame retardants. To protect the further process of treatment, these hazardous parts have to be removed, otherwise they may contaminate the outcome of the recycling or disposal process. (Unger et al., 2017)

Due to the above mentioned divers composition of the products, it is very difficult to generalize the material outcome of the recycling process. Iron and steel are the largest group of material found in WEEE by weight. Followed by plastic with 21% and non-ferrous metals, including precious metals by 13% of the total weight. The amount of pollutants and hazardous substances has declined over the last years. (Ongondo et al., 2011)

The extraction process of the precious resources is always an economical question. The recycling good must be able to compete with primary resources at the economical as well as at the ecological level. Regarding to Martens and Goldmann (2016), there are five rules to enter the market with a recycling good. First, the recycling product must be able to substitute the primary resource in quality. The secondary resource must be integrated into new production processes without any loss of quality for the outcoming product. Second, there has to be a market for this good, which is able to adopt in variations of quantity and quality, as well as there must be sufficient quantity of sale. Third, the dimension and the spatial distribution of the recycling facilities have to be optimized to work cost efficient. Fourth, the whole system has to be very flexible and adaptable, especially in the WEEE sector as the requirements change frequently. Hence technology changes rapidly, also the recycling processes have to adopt. Fifth, the complete cost structure has to be similar and competitive to the cost structure of primary resources. If this is not the case, as for example for sludge or dust, the disposal contractor has to pay for the treatment.

Table 2 shows the categories of WEEE regarding the WEEE directive and some examples to provide insight into the diversity of the different WEEE waste management has to deal with.

Category 1: Large household appliances (external dimension more than 50 cm)	Large cooling appliances, washing machines, electric heating appliances
Category 2: Small household appliances (no external dimension more than 50 cm)	Vacuum cleaners, toasters, scales
Category 3: IT and telecommunications equipment	Centralised data processing equipment: Mainframes, minicomputers, printer units; personal computing equipment: notebooks, cell phones, printers
Category 4: Consumer equipment and photovoltaic panels	Radio sets, photovoltaic panels
Category 5: Lighting equipment	Straight fluorescent lamps, compact fluorescent lamps, low pressure sodium lamps

Category 6: Electrical and electronic tools (with the exception of large-scale stationary industrial tools)	Equipment for turning, milling, sanding, grinding, sawing, cutting, shearing, drilling, making holes, punching, folding, bending or similar processing of wood, metal and other materials
Category 7: Toys, leisure and sports equipment	Hand-held video game consoles, sports equipment with electric or electronic components, electric trains or car racing sets
Category 8: Medical devices (with the exception of all implanted and infected products)	Radiotherapy equipment, cardiology equipment, analyzers
Category 9: Monitoring and control instruments	Smoke detector, thermostats, heating regulators
Category 10: Automatic dispensers	For hot drinks, for solid products, for money

Table 2: categories of WEEE according to the WEEE directive with examples

Dimitrakakis et al. (2009) revealed a study in 2009 analyzing small WEEE found in Germany, in municipal solid waste with the following composition of material, sorted by the ten categories of the EU WEEE Directive. Table 3 shows the result of the study in mass percent. The eleventh category results in products, which could not be categorized. These are for example illuminants from households, car electronics, frames, wires etc. Regarding the gathered data of this study the largest share is by various polymers with nearly a third of the total mass. Followed by diverse electronic components with a quarter of the share. The share of ferrous metals is also significant. Neither negligibly is the amount of printed wiring boards (PWBs), non-ferrous metals, bonded materials and wires, even though the amount is small against the total mass. The fraction of batteries, rubber and other components plays only a small role regarding to Dimitrakakis et al. (2009).

Material fraction	EEE Category										
	1	2	3	4	5	6	7	8	9	10	"11"
Ferrous metals	51.60	8.99	25.27	12.04	10.40	13.32	2.50	7.42	0.27	–	27.92
Non-ferrous metals	2.89	8.22	0.09	1.08	–	2.69	0.23	8.12	–	–	0.70
Plastics	9.85	40.70	27.49	28.17	24.19	9.18	83.60	29.27	76.62	69.48	34.26
Rubber	0.05	0.69	0.79	0.54	–	0.21	1.12	3.25	0.22	–	0.43
Cables	3.00	7.55	3.34	2.80	0.77	7.02	2.26	–	0.46	8.50	6.54
PWBs	0.08	0.52	10.17	6.77	–	0.92	3.84	–	22.44	4.33	0.72
Electr(on)ic components	28.16	18.41	4.45	38.48	64.64	66.11	3.92	20.09	–	1.48	13.78
"Bonded" materials	4.35	11.77	11.09	5.28	–	0.53	0.004	–	–	15.32	7.29
Various	–	2.53	14.03	3.00	–	0.04	1.91	31.84	–	–	3.33
Batteries	–	0.49	2.63	1.74	–	–	0.53	–	–	0.33	5.04
LCDs	–	0.12	0.64	0.08	–	–	0.09	–	–	0.56	–

Table 3: Material composition for each category of the WEEE samples (%, w/w) (Dimitrakakis et al., 2009)

As can be seen from this data, the loss of resources is high if WEEE is not treated correct. Referring to Martens (2011) the number of recovered elements from WEEE is low. In developing countries, only up to five elements are recovered under unfavorable ecological and social conditions. With state of the art technique as they are used in the European Union up to 19 elements can be recovered. For this reason, transboundary shipment for electronic waste is regulated by the Basel Convention, as the exporting country has to make sure, that the importing country treats WEEE in a sound manner. This convention was signed by all 164 signatory countries except Afghanistan, Haiti and the United States of America (Widmer et al., 2005). The subject of transboundary shipment was adapted by the WEEE directive, article 10. WEEE and/or hazardous waste is only allowed to leave the EU, if the exporter can prove that the waste is treated as required in the WEEE directive (Europa.eu, 2017). Never the less, through the legal loophole of second hand trading to bridge the digital dived, massive amounts of WEEE get deported illegal (Nnorom and Osibanjo, 2008). For example, in 2010 Nigeria imported 1.2 million tons of EEE, whereof 35%- 70% were second hand (Schluep et al., 2011). Other studies assume a rate of 50% (Schluep, 2012). The rest was fabric new EEE. Assuming that 30% of the imported EEE does not work and therefore should be declared as WEEE, 50% of it can be refurbished in Nigeria. That means, at least 15% (100 000 tons) of the imports are illegally brought to Nigeria.

3.3 Social, environmental and technological drivers as engine for adapting waste management strategies

People have always had drivers for waste management issues. Starting in the Middle Ages, were people collected waste as fertilizer or to gather useable or sellable objects. But with no social network, as poor people had other sorrows and the rich did not want to clean up after the poor, it was of no real matter and regularity. In the 1800s the communities started to collect waste, as the relation between epidemics and the terrible sanitary conditions came up. At the beginning of the 20th century the main driver was still public health, but it evolved to first industrial recycling activities during the first and second world war. In the 70ies of the 20th century waste management found its way to the political agenda, driven by environmental issues. Nowadays, there are plenty of drives for waste management in developed countries, but their roots can all be found in the history of waste management. While treating waste for public health is taken for granted and no longer a major driver, the environmental protection is permanently evolving. From “Waldsterben” and acidification of aquatic systems up to the actual topic of global warming. Hand in hand with environmental drivers came the “resource drivers”. The main drivers for resource aspects have been the implementation of the waste hierarchy and the EU landfill directive. Both lead to leaving an end of pipe waste management system towards a “resource management”. This new driver is called “closing the loop” and can be found in the concept of sustainable consumption and production, while decoupling economic growth and waste increase (Wilson, 2007). According to Wilson (2007), the beginning of “resource drivers” was more impacted by statutory targets, than by the thought of resource recovery. But with an increasing market for electronic goods due to globalization, the interest in recovering precious resources out of WEEE is increasing. Some rear earths used in IT equipment and cell phones can only be mined in conflict areas in developing countries under cruel conditions. Moreover, the constant depletion of resources for EEE production increases the prices for primary resources. Hence recycled resources get competitive. This excursion about drivers in waste management shows, that the systems reacts to needs and challenges in the society. However, the system only reacted after an issue popped up and caused a problem. Waste got collected after people got sick. Recycling started because of resource shortages during the wars. A change in landfill operation followed dramatic environmental problems. So, every time new drivers occurred or new measures were set, something negative had happened bevor. Therefore, it is important to act presciently in order to perceive new upcoming issues before they become problematic. New waste streams should be addressed early enough and regulated if necessary.

4. The growing LED market, LED technology and their impact on the environment

This chapter gives an overview of the uprising market of LED products, presents the basic technology behind LEDs and the possible environmental impact after end of life.

4.1 The triumph of the LED

When LEDs were introduced to the market in the 1960s, they were mainly used in calculators, digital watches and testing equipment. It took until the 1990s to develop red, green and blue LEDs. With this achievement it was possible to use them in a wide range of applications such as large area displays, aerospace and traffic lights to name a view. Further on with the technology of nanoscale production and the development of white LEDs the application opportunities got manifold. They are used as general lighting as well as in nearly every display as background lighting. LEDs have some main advantages against other lighting systems as they are, a life span of over 50 000 hours, a highspeed response time, reduced dimensions, a better thermal management, nearly no mercury, no infrared radiation and are therefore better for the surrounding health as well as they are dimmable without any energy losses. For all these benefits LEDs can be seen as a good way to save energy and therefor reduce greenhouse gases. Moreover, the global energy consumption for general lighting is about 19% and increasing, as the intensity of technologies also increases in developing countries. Therefore, LEDs used for general lighting can be a real energy saver, even if the price was eight times higher than for a comparable halogen lamp in 2009. Moreover, prices decrease and the long lifespan of LEDs make them more cost efficient than any other light sources. (Dalpaz de Azevedo et al., 2017)

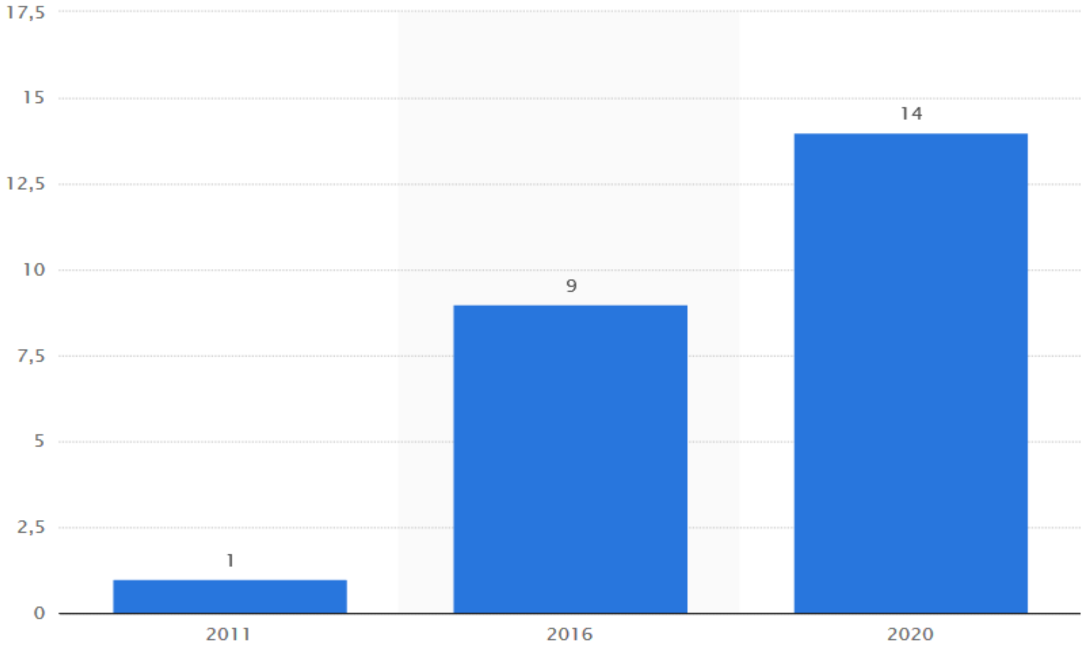

Figure 2: market volume of LEDs in Europe in Billion Euros (Statista, 2017a)

This development can be seen in figure 2, as the market volume of LEDs in Europe grew from one billion Euro in 2011 to nine billion in 2016 and is projected to increase up to 14 billion Euro in 2020 (Statista, 2017a). This increasing prognosis are not only limited to the European market, but can be seen globally.

4.2 The technical background of LEDs

The basic principle of function, of a LED can be seen in figure 3. LEDs use a p-n junction and a single semiconductor that generates a transition interface. Under forward bias conditions, the p region (positive charge) receives electrons, while holes are injected into the n region (negative charge). Photons, and therefore light is emitted during the recombination of the minority and majority carrier at the p-n junction. The struggle with this basic type of LED is, that the entire structure has the same composition and therefore self-absorption of the emitted light is very high. For that reason the efficiency is low. To improve LEDs and reduce the self-absorption different epitaxial structures are used in a single diode. These so called heterostructures minimize the photon absorption in the n region and double the efficiency of the diode in comparison to LEDs with homo-structures. Efficiency can further be increased by nano-scale production methods, as with smaller semiconductors the transmission problems between the interfaces decrease. For white LEDs a RGB (red, green, blue) systems can be used as well as multiple phosphorus techniques. The phosphor layer method is the commonly used thing. It has a higher luminous efficiency and is less expensive, because RGB systems still need a highly complex control system. (Dalpaz de Azevedo et al., 2017)

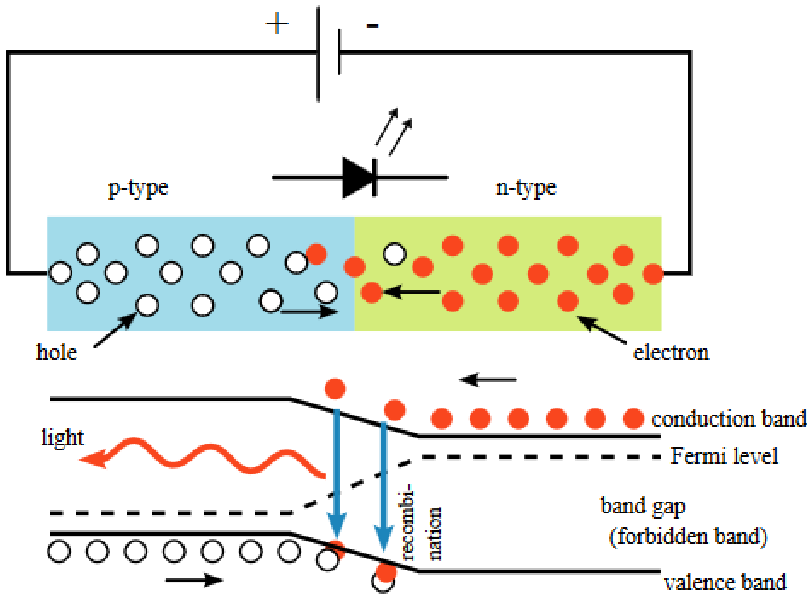

Figure 3: basic function principle of light emitting diodes (WIKIPEDIA, 2017)

4.3 The environmental impact of LEDs

Within this chapter the used material and its possible hazardous properties regarding waste management issues are described. A study from 2011 by Lim et al. (Lim et al., 2011) examined the possible environmental impact of LEDs. The study used standardized leachability tests. The outcomes have been compared to the thresholds of the US federal and California state regulations to find out, if LEDs have to be classified as hazardous waste. At this point it has to be said, that California state regulations are stricter than the US federal regulation. Moreover, the study used material lifecycle impact and hazard assessment methods to evaluate LED based resource depletion and their toxicity potential.

LEDs normally use group III-V semiconductors, hence they can contain arsenic, gallium, indium and antimony. All these materials can cause a threat to human health and the environment. Moreover, leads, wires, solders, glues and adhesives are used to assemble LEDs. All this "side" materials contain different metals such as gold, copper, silver, nickel and lead. The possibility of brominated flame retardants used in the plastic housing was not considered by this study.

The study used nine different 5-mm pin-type LEDs in five different colors as they were red, blue, green, yellow and white. The colored LED represent low (50 to 400 mcd) and high (900 to 9 000 mcd) intensities. The low intensity LEDs are used for single indicator purposes, whereas the high intensity LEDs can be used for outdoor signaling. The white light emitting diodes, with 10 000 mcd are mainly applied for display background lighting.

The results of the tests show, that the levels of iron, copper and nickel are high in LEDs of all colors and intensities. The level of gold and silver used in LEDs is lower. Also, the group III-V semiconductor materials are much lower. The results can be seen in table 4.

		LED (color/intensity)								
substance	TTLC threshold	red/low	red/high	yellow/low	yellow/high	green/low	green/high	blue/low	blue/high	white
aluminum	N/A	97.0	158.0	104.0	156.0	79.6	156.0	153.0	73.4	84.5
antimony	500	15.4	2.0	2.8	1.9	3.6	2.5	1.3	1.5	25.9
arsenic	500	11.8	111.0	8.0	84.6	7.8	15.2	5.7	5.4	ND
barium	10000	ND	ND	ND	ND	ND	ND	ND	ND	ND
cerium	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND
chromium	500(VI);2500(III)	138.0	28.6	32.7	27.9	84.1	49.3	50.9	30.3	65.9
copper	2500	87.0	**3818.0**	956.0	**2948.0**	1697.0	**3702.0**	**3892.0**	2153.0	31.8
gadolinium	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND
gallium	N/A	135.6	95.0	63.8	79.1	75.6	3.1	2.1	1.5	3.8
gold	N/A	39.8	45.8	30.5	30.1	40.2	176.3	32.5	118.6	115.9
indium	N/A	3.4	1.7	ND	ND	2.5	ND	ND	ND	ND
iron	N/A	285558	363890	300905	398630	310720	395652	339234	256499	311303
lead	1000	**8103.0**	8.9	7.7	ND	5.0	ND	ND	ND	ND
mercury	20	ND	ND	ND	ND	ND	ND	ND	ND	ND
nickel	2000	**4797.0**	**2054.0**	1541.0	**2192.0**	**2442.0**	**2930.0**	1564.0	1741.0	**4083.0**
phosphorus	N/A	114.2	ND	58.4	ND	78.5	91.8	79.1	84.3	110.8
silver	500	430.0	409.0	248.0	336.0	270.0	306.0	418.0	**721.0**	**520.0**
tungsten	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND
yttrium	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND
zinc	5000	48.2	66.2	36.5	63.6	41.8	62.5	42.6	36.7	49.2

[a] The values in bold indicate that the TTLC results exceed the regulatory limit. The unit of measurement is mg/kg. [b] N/A: Not Applicable. [c] ND: Not Detected.

Table 4: results of Total Threshold Limit Concentrations in mg/kg (Lim et al., 2011)

The overall weight of these metals corresponds to a third of the total weight of the LED sample, no matter which color. The remaining weight is the plastic housing. Under

California state regulation most LEDs would be classified as hazardous waste. Table 4 shows, that all LEDs except for yellow low intensity LEDs exceed the level of copper, lead, nickel and/or silver. The study also claims, that there are no thresholds for some detected metals as there is too little knowledge of their impact on humans and the environment. Moreover, under US federal regulations only lead in low intensity red LEDs would exceed the threshold. Hence, Lim et al. (2011) recommend to establish uniform thresholds worldwide to challenge the industry towards a sustainable and more environmental friendly design of LEDs.

The same study also deals with the resource depletion potential of producing LEDs. The substances with the highest resource depletion potential are silver and gold, although they only occur in small amounts in the investigated LEDs. If the metal combination used for LEDs will stay the same, considerable impacts on the deposit of gold and silver will occur. Gold is used as conductive metallic wire to connect the pin type electrode with the LED chip. Gold has a very low thermal and electrical resistivity. Therefore, damages caused by a poor thermal management can be prevented. Silver is used for reflecting the light from the LED chip. As this study only deals with pin type LEDs, it has to be said, that the upcoming of surface mounted LED will need even more gold and silver because of the technical structure.

Continuing with the toxicity potential, copper, lead, iron, nickel and silver contribute the most to the hazardous potential. Each of these metals contribute at least 10% to the overall hazardous potential of all 14 metals contained in LEDs, whereby the highest toxicity potential shows the low intensity red LED, because of its high concentration of lead. In general, high intensity LEDs have a higher toxicity potential, than low intensity, because of their higher contend of copper, iron and nickel. The higher content results out of the higher energy consumption and therefore the higher diameter in wiring.

Further on a life cycle impact assessment was made to find the relative contribution of each metal to the toxicity potential. Arsenic and lead were found to cause cancer, lead and copper are toxic and copper and nickel have been found ecotoxic. Looking at the single LED, low intense red is again the one with the highest cancer and toxicity potential. It contains arsenic and lead.

Except for low intensity yellow and white LEDs, all LEDs have an ecotoxic potential due to copper and/or nickel. The most harmless LED color is white, as it contains less copper and no arsenic.

Overall Lim et al. 2011 suggest, that this new information should lead to a sound product design. Moreover, if new material is used for the production, assessments like this should be done to be aware of every risk, as the market for LED is growing rapidly.

5. Results

As can be seen in Chapter 2. the results are based on a survey and an analysis of four sample products representing the four product groups. Chapter 5.1 presents the outcomes of the survey and tests the four hypotheses. Chapter 5.2 deals with the outcomes of the product analysis.

5.1 The Survey

The survey was spread as a paid Facebook advertisement to reach people outside the filter bubble of the author. The goal was to picture the results as close as possible to reality. To compare the structure of the sample to the population, the highest level of education was used. Table 5 shows the dispersion in the survey and the latest figures from Statistik Austria (2017a).

	compulsory school	**apprenticeship**	**vocational middle school**	**grammar school**	**vocational high school**	**college**	**university**
survey	5,8%	17,3%	8,1%	18,5%	11%	3,4%	35,8%
Statistik Austria (2017a)	19%	34,3%	15,1%	5,7%	8,4%	3,3%	14,1%

Table 5: Comparison of dispersion of level of highest education between survey and Austrian statistical data [n=173]

As can be seen, these two dispersions do not corelate well, especially consumers with an university degree are over represented in the survey. But regarding to von der Lippe and Kladroba (2002) the correlation between a survey and its population does not necessarily impact its quality, as it is the nature of a random sample. Even if the survey correlates with the population there is still the possibility of having a sample, which is not representative. This problem can be minimized by the sample size. It has to be said, that the sample size of this study, was limited by an economical shortage and time limitation.

The population of this survey are all households in Austria, which are 3 865 000 private households with an average of 2.22 person in the year 2016 (Statistik Austria, 2017b). The rate of return was about 196 questionnaires, whereas 173 of them were useable. The assumption was made, that every questionnaire represents one household in Austria. The sample size is 173 households.

5.1.1 Amount of investigated LED products in Austrian households

At first people were asked how many of the defined LED products they have in their household. In figure 4 the dispersion of the investigated LED products in Austrian households can be seen.

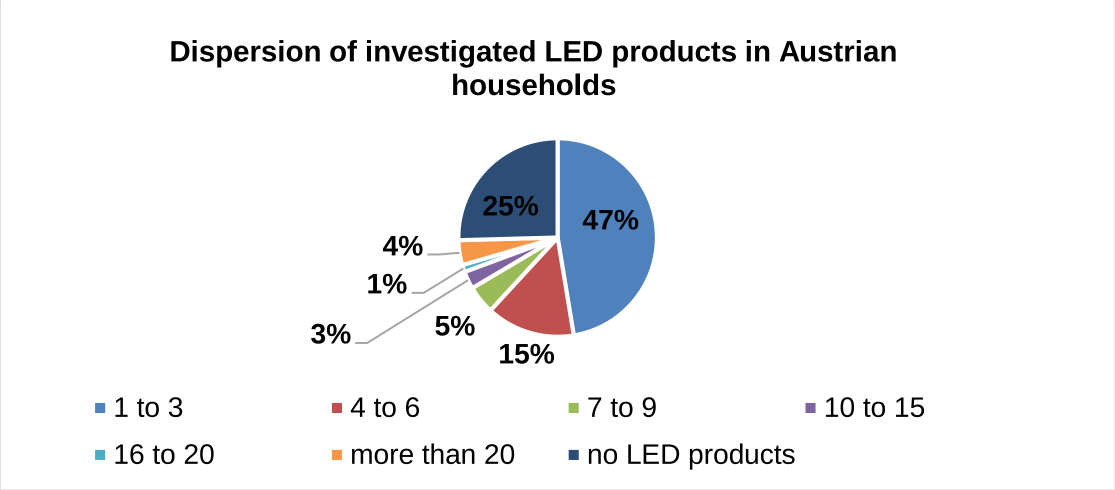

Figure 4: percentage of investigated LED products in Austrian households [n=173]

As can be seen, nearly 50% of the households own 1 to 3 products. A quarter of all households do not own one at all. With these figures and the given number of households in Austria in the year 2016, calculations were made to obtained the quantity. For further calculations all three, the minimum, the maximum and the mean will be used. The results can be seen in table 6.

Minimum, maximum and mean number of investigated LED products in Austria	
minimum	7 663 106
maximum	12 627 466
mean	10 203 592

Table 6: calculated minimum, maximum and mean number of the investigated LED products in Austria

People were asked to name the quantity of the investigated products, regarding to the four different product groups. The results for each category can be seen in the appendix 2. Figure 5 shows the dispersion between accessorize, apparel, decoration and toys.

As can be seen the largest product group is decoration with 35% followed by toys with 28%. Accessorize takes 23% for it and at last apparel with 13%. Table 7 deals with the actual quantity of the different product groups.

Quantity of investigated LED products, split in four product groups in Austrian households				
	accessorize	**apparel**	**decoration**	**toys**
minimum	1 649 234	899 582	2 582 134	2 049 048
maximum	3 648 305	2 049 048	5 447 469	4 397 956
mean	2 648 769	1 474 315	4 014 801	3 223 502

Table 7: calculated quantity of the investigated LED products, split in four product groups in Austrian households

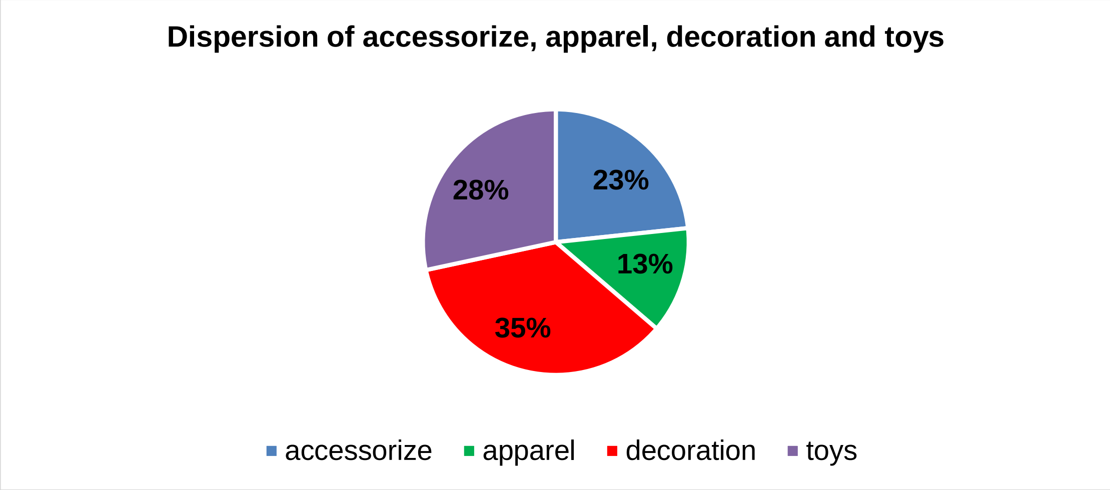

Figure 5: dispersion of accessorize, apparel, decoration and toys [n=173]

According to the calculation it is estimated, that there are between seven and 10 million LED products in Austrian households.

5.1.2 Disposal behavior for the investigated LED products

The survey also covered the topic of disposal, as the investigated products may not be always recognized as WEEE after the end of life. Therefore, it is important to analyze the disposal behavior and suggest counter actions, if there is a lack of awareness. The participants of the survey had to provide information regarding their disposal behavior for each product group. As every product has its own characteristic, people may think of different end of life actions. For example, getting rid of apparel with LED application at an old cloth collection. People had to choose between the disposal in residual waste, e-waste, plastic waste, old cloth collection, passing it on or selling it and their own suggestion. Starting with LED accessorize, figure 6 shows the results of the survey.

By getting rid of LED accessorize, disposing it in the residual waste (39%) is head on head with the opportunity of e-waste. Passing it on or selling, is an option for 16%. Only 3% would use plastic waste. 5% would choose another option. As they were free to fill in their suggestions, it is possible to count these 5% to the disposal of e-waste. All 5% suggested to dispose their item at special facilities. Hence, this 5% of LED accessorize, would also end up in the e-waste.

Moreover, figure 7 shows that people disposing their LED decoration have slightly other preferences. The largest group would trash the items with the residual waste. Only 31% percent would use the option of e-waste. Passing on and plastic waste, would only be used by a small group. 9% would again use special facilities, by which the item will get to e-waste. Only one sample would use the opportunity of the take back system for electronic goods.

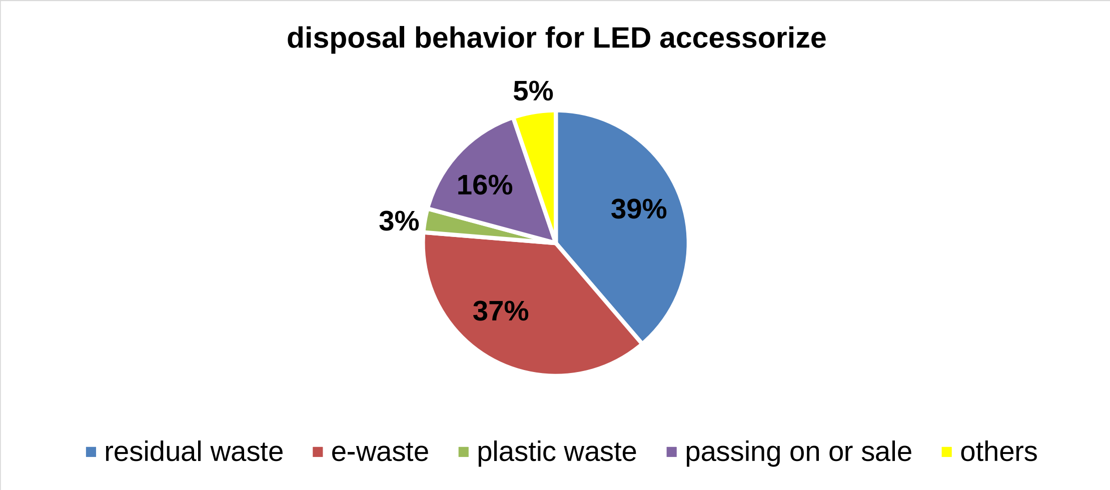

Figure 6: disposal behavior for LED accessorize [n=173]

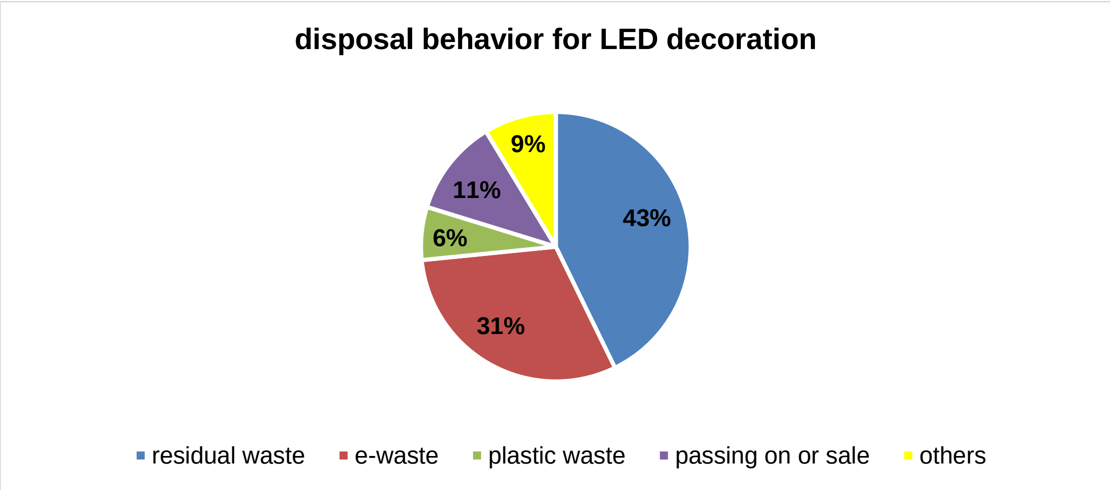

Figure 7: disposal behavior for LED decoration [n=173]

If one takes a look at figure 8, the disposal behavior for LED apparel is completely different. Since the participants, had the opportunity to choose the old cloth collection, it was the choice of 62%. Except for the category “others” with 2%, all other categories are evenly spread. In “others”, suggestions as dissembling with subsequent separate disposal were made.

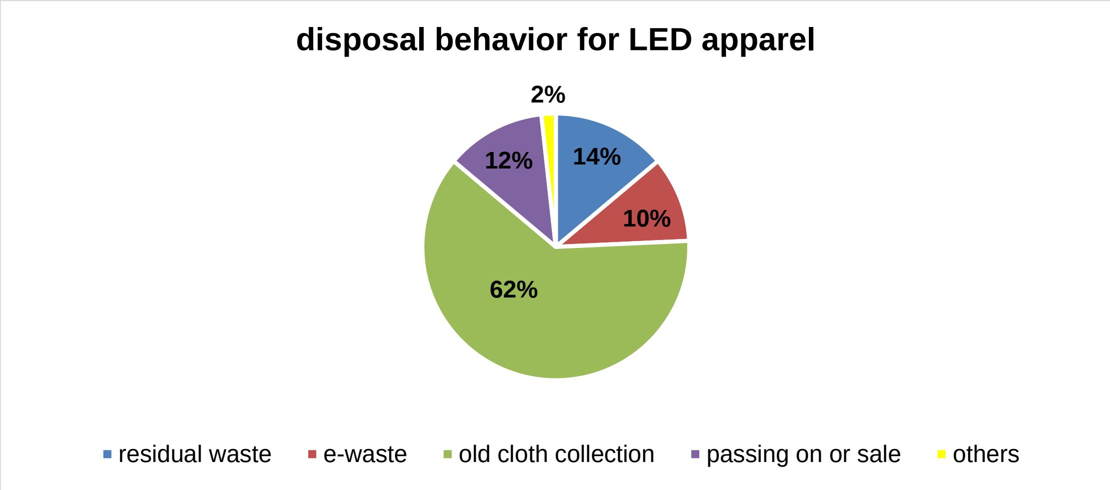

Figure 8: disposal behavior for LED apparel [n=173]

Figure 9 pictures the dispersion of disposing LED-toys. Regarding the survey, a third of the sample would pass toys on or sell them. Nearly 30% would throw them into the residual waste and another 20% into e-waste. Only 10% would use the plastic fraction. In category "others" people assumed to dissemble the items and dispose the diverse parts separately or bring them to special facilities.

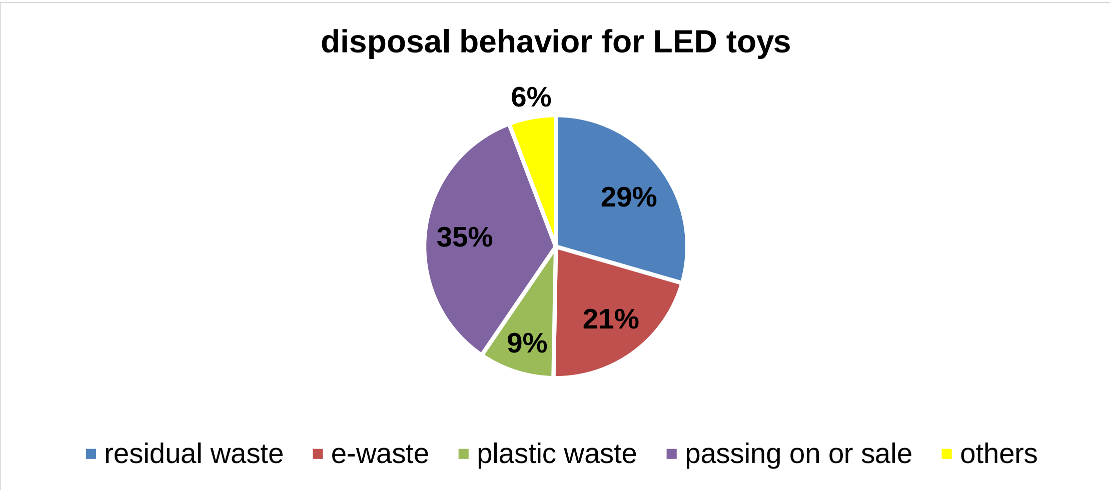

Figure 9: disposal behavior for LED toys [n=173]

Overall people tend to dispose the investigated LED items in the residual waste by 31%. The second rank is the option of e-waste disposal with 25%, followed by the plastic waste/ old cloth collection fraction with 20%. "Passing on or selling" is used 19% of the time. The category "others" with 5% has a clear tendency for separate collection in special facilities, whereas it could be counted to e-waste.

5.1.3 Consumer behavior on investigated LED products

To get a picture of the waste potential of the investigated LED products, it is also necessary to take a look of the consumer behavior. Figure 10 and 11 show, how people got their products and how long they are planning to use them.

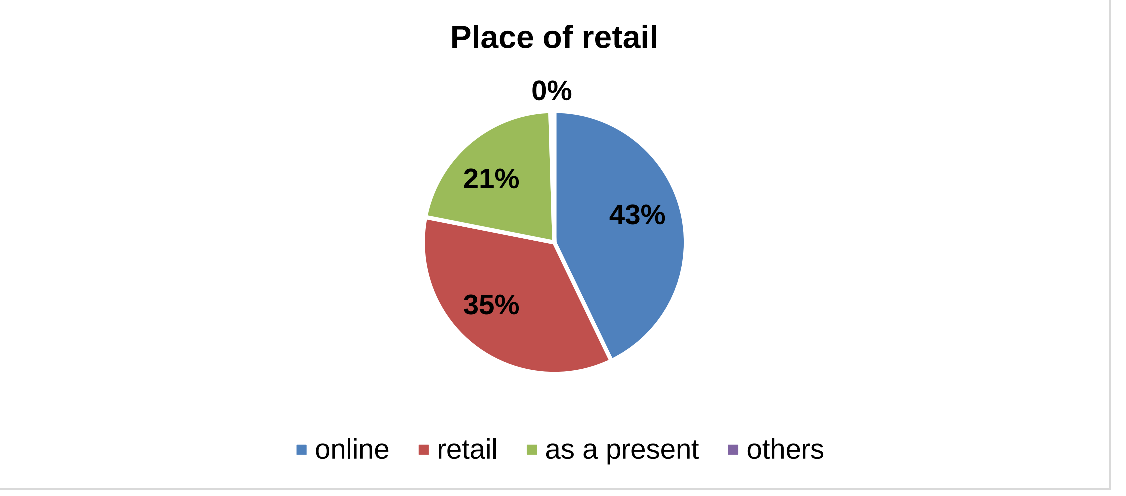

Figure 10: place of retail [n=173]

The pie chart (figure 10) shows, that 43% percent of the sample bought their products online. 35% bought them at a local retailer. Only one sample bought its product secondhand. The 21% of the sample, who got the LED gadget as a present should be spread proportional to “retail” and “online”, as someone must have bought it for them. This means, that 55% use online market places and 45% use local retailers.

More than half of the sample suggest to use their LED gadget longer than one year (figure 11). 21% will use them for at least 1 to 6 months.14% suggest a service life of 7 to 12 months and 13% are going to use their products only once.

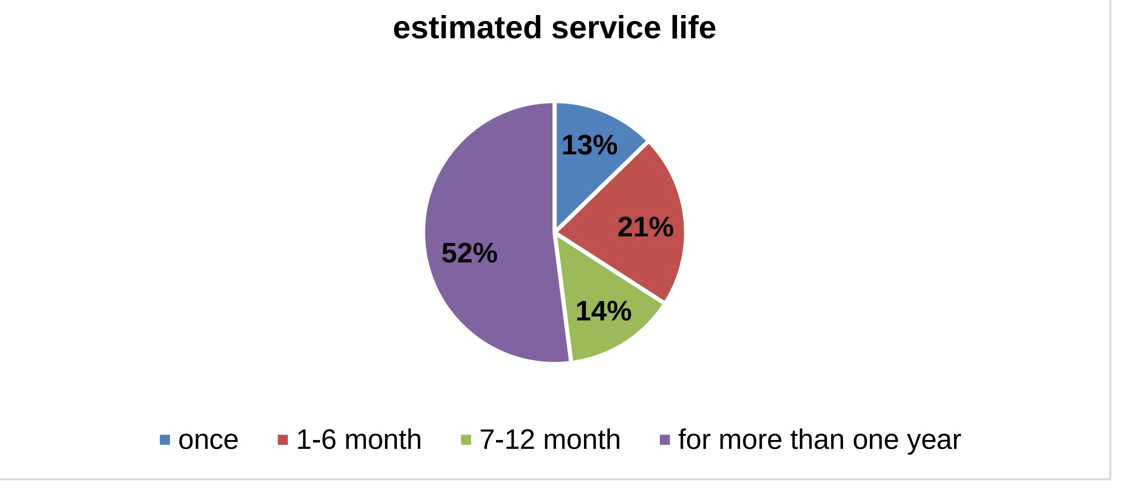

Figure 11: estimated service life [n=173]

5.1.4 Demographical data

To complete the survey demographical data, such as gender, age, highest education, household size and living area have been surveyed. 57% of the sample was male and 43% female. 61% of them are currently living in urban areas, whereas 39% are residents in rural areas. Furthermore, the mean household size in this survey was by 2.88 people. Figure 12 shows the age of the consumers. The largest group with 31%, represents the age 18 to 24.

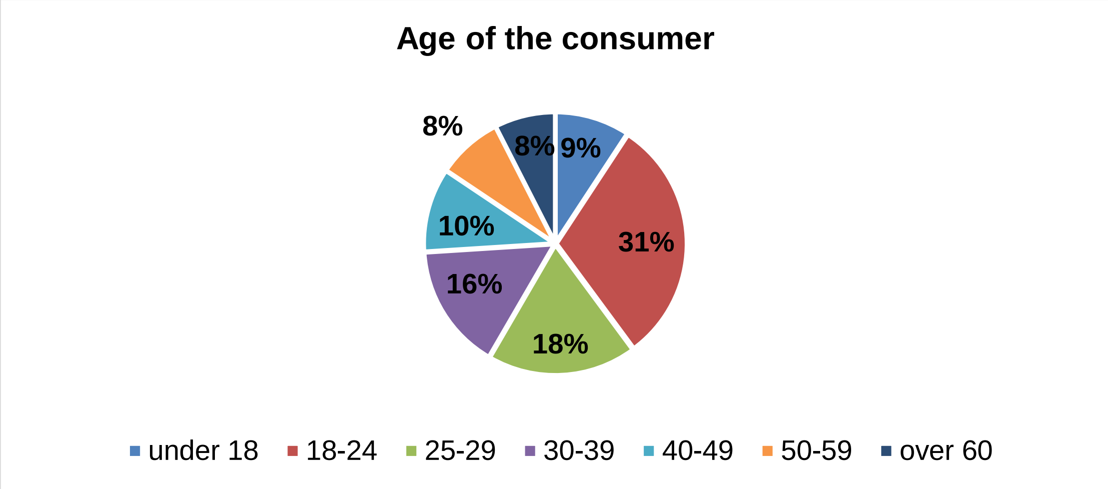

Figure 12: age of the consumer [n=173]

The dispersion by "highest education" can be seen in table 5 at the beginning of chapter 5.1.

5.1.5 Relations between the datasets

With the data of this survey relations between different demographical data and the amount of possessed LED items can be shown. The goal was to find the evidence for a relation between age, highest education and the amount of the investigated LED products. If there is a relation between all these factors, it would be possible to take target-group-specific actions, if there is a misdemeanor on the subject of disposal.

The first hypothesis of a decreasing number of gadgets with an increasing level of education, was proofed right. In figure 13 it can be seen, that with an increase of education people buy les LED gadgets, except for the collage sample, which seems to be an outlier. The range goes from 2.2 investigated LED products by the university sample to a mean of 5.5 items with the group of apprenticeship.

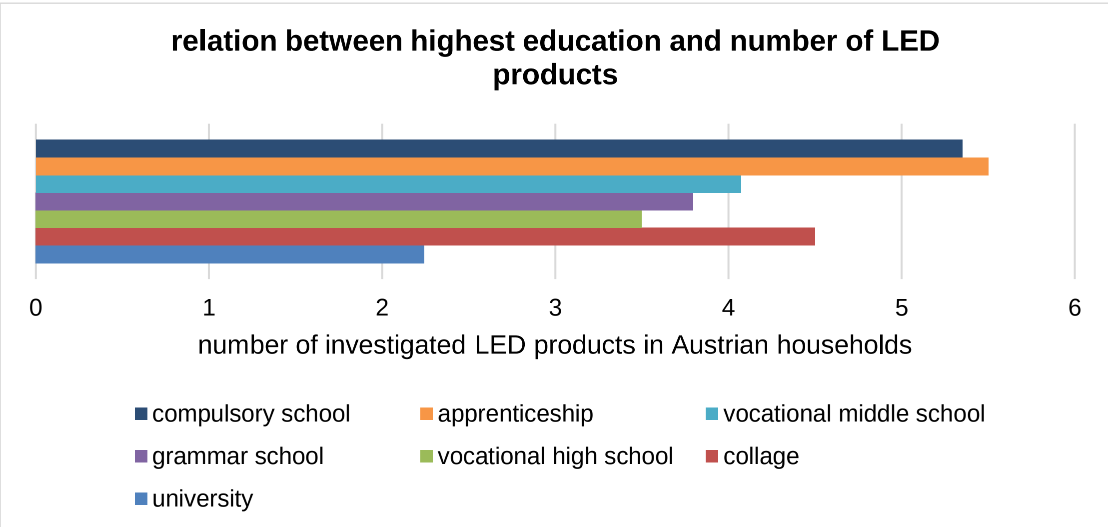

Figure 13: relation between highest education and number of LED products

The second hypothesis of a decreasing number of the investigated LED products in Austrian households by increasing age was also processed. As figure 14 shows, the number of possessed items decreases with the sample getting older. Again, there is an outlier by the group of people in the age of 25 to 29. People over sixty own in mean 1.9 LED items, whereas the sample under the age of 18 comes to an average number of five products.

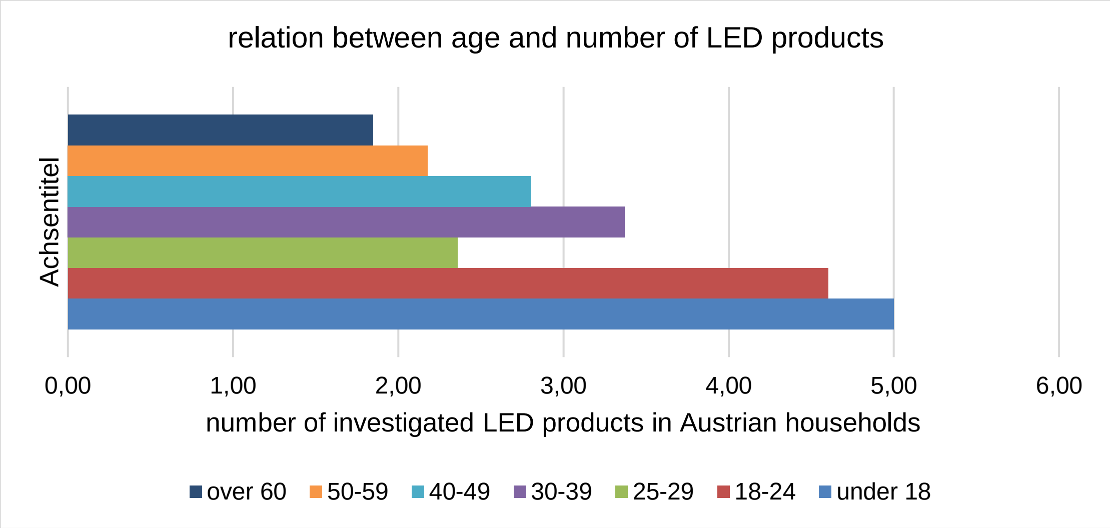

Figure 14: correlation between age and number of LED products [n=173]

Another interesting relation could be found between age, level of education and the disposal behavior. The author hypothesis an increasing awareness for disposing LED products by a higher level of education. On the other hand, the author hypothesis that younger people have a higher awareness for the disposal issue than the older part of the sample.

The result for a relation between the level of education and disposal behavior can be seen in figure 15.

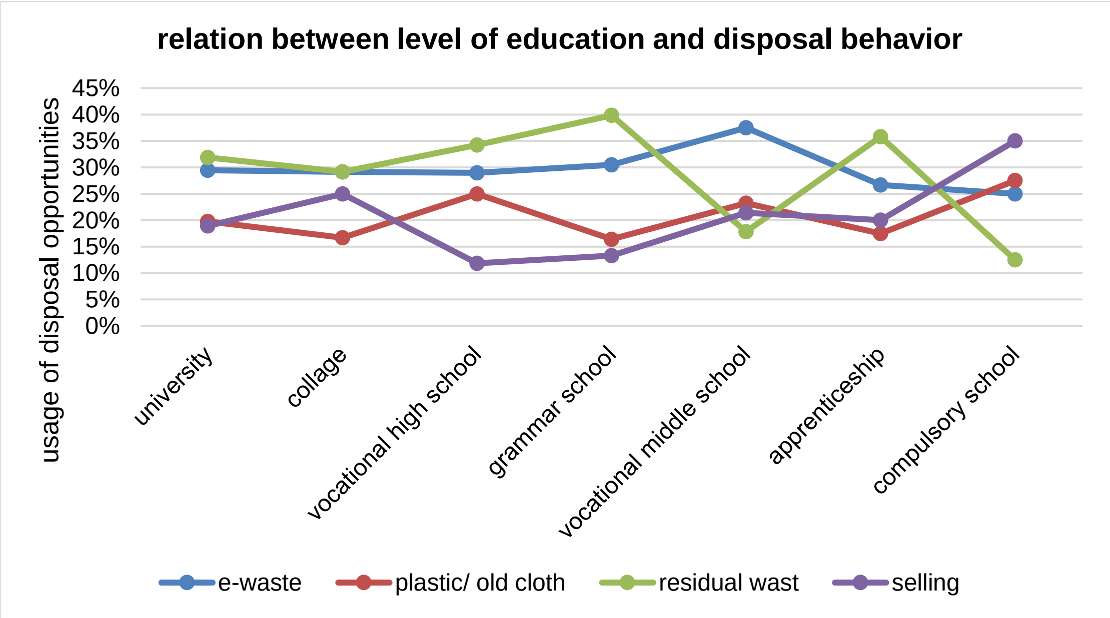

Figure 15: relation between level of education and disposal behavior [n=173]

The hypothesis of an increasing awareness for disposing LED items with an increasing level of education could not be confirmed. The graphic shows, that the percentage of people using e-waste is more or less constant over all levels of education. It has its peak by the sample of “vocational middle school” and it decrease slightly for “apprenticeship” and “compulsory school”.

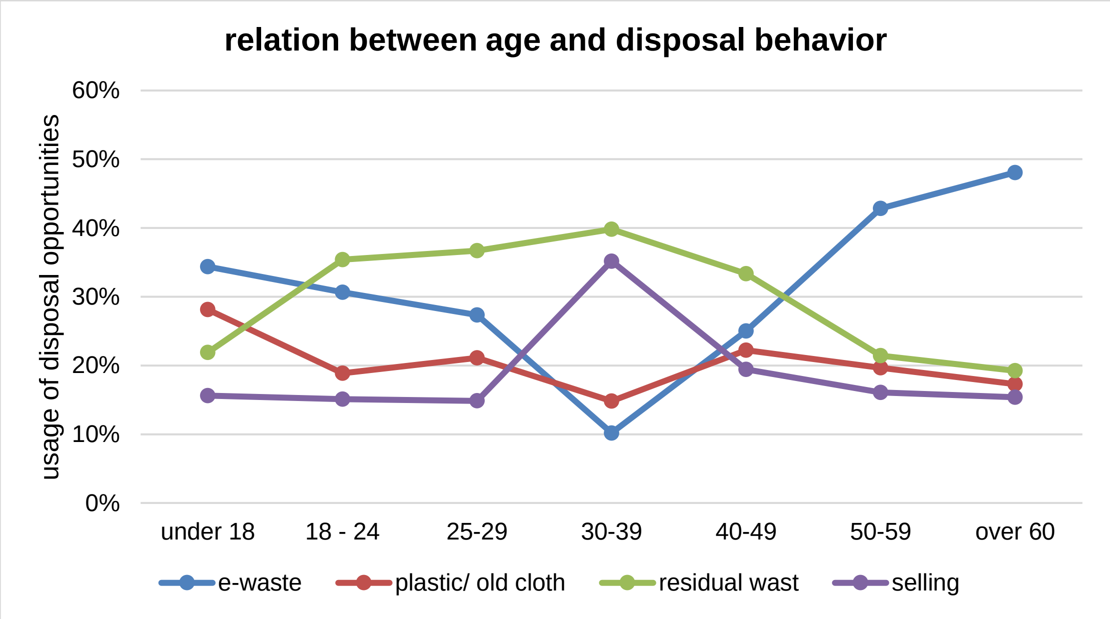

Figure 16: relation between age and disposal behavior [n=173]

Figure 16 deals with the relation between age and disposal behavior. Again, the hypothesis has to be overruled, as no clear relation can be seen. By increasing age, the rate of people using “e-waste” drops until the age of 39, but rises again and reaches its peak in the sample “over 60”. Rather there is a negative correlation between “e-waste” and “residual waste”.

The next relation could be between the region where people live and the mean amount of owned LED products. If there is a clear difference between rural and urban areas, it is also worth to figure out if there is any difference in the disposal behavior between these two factors.

The survey revealed, that people in rural areas own about 5 LED items in mean, whereas in urban areas the mean is by 2 items. These figures show, that people in rural areas own 112% more of the investigated LED items compared to urban areas. Figure 17 shows the difference in their disposal behavior.

People in rural areas are more likely to use the option of recycling like e-waste, plastic waste or old cloth collection. On the other hand, people from urban regions are more likely to dispose their LED items in the residual waste or sell them.

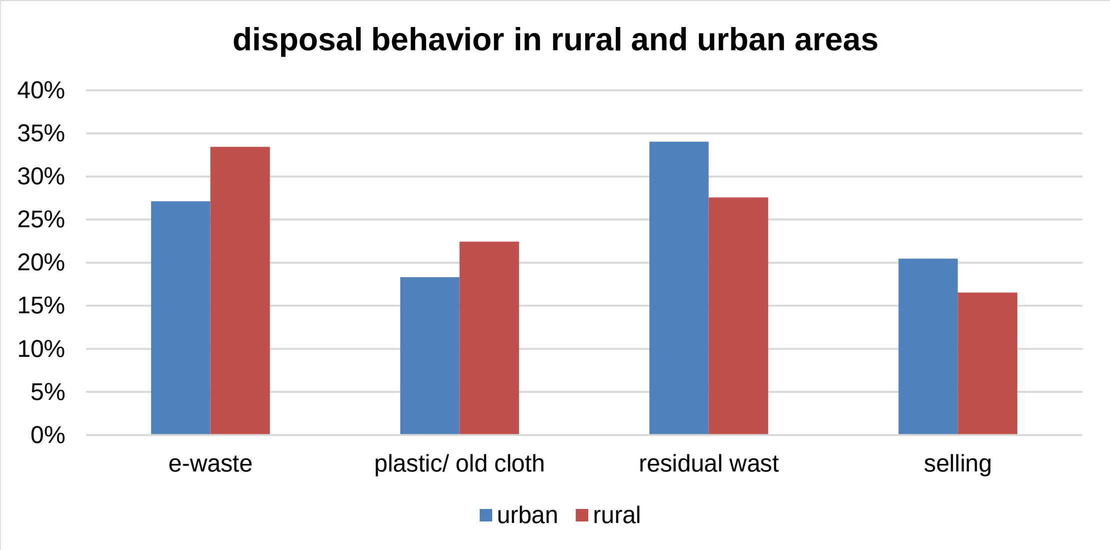

Figure 17: disposal behavior of the investigated LED products in rural and urban areas [n=173]

5.1.6 Interpretation of the data

After the quantitative evaluation of the data, it is necessary to interpret the results. What do the results tell us about the consumer and disposal behavior and why is it like that?

Starting with the dispersion of the four different product groups as it can be seen in Figure 5. The domination of decoration (35%) and toys (28%) is obvious. This is for the simple reason, as toys and decoration have been illuminated for a longer time, and cheaper LED technique as well as new technologies open new opportunities. So, people are used to buy illuminated products in the sector of toys and decoration. On the other hand, illuminated accessorize and apparel are more or less a new phenomenon on the market. The largest share of these products is only possible because of advanced LED and accumulator battery technology.

Looking at the disposal behavior it is quite alarming that 31% would use the residual waste to dispose the investigated LED products. One reason for this behavior could be a shifted awareness. If a LED product does not work anymore, for what reason so ever, people may think of it as “normal” item, as one requirement in the definition was “Its original function can be complied without LEDs”. So, the owner may not think of it as an electronic product, but as a decoration, apparel, toy or accessorize and therefore chooses another way of disposal. Even if the electronic parts such as PCBs, wires, LEDs or batteries/accumulators are still there. Moreover, people throw small WEEE more likely into the residual waste than larger applications (Oguchi et al., 2011). According to Rotter et al. (2006) the part of small WEEE in residual household waste is about 0.8% of the annual household’s waste. This is 2.6 kg per inhabitant per year in Austria. According to another study from the Netherlands (Huisman et al., 2012) 26% of all small WEEE application end up in the residual waste. Therefor it is not surprising, that nearly one third of the sample would dispose the investigated LED gadgets there.

25% of the sample prefers the option of e-waste. It is less than the “residual waste” fraction but if the answers of “others” is considered and added, the percentage goes up to 29. Most of the answers consider to use special facilities such as waste material collection facilities. As nearly all small WEEE collection in Austria happens by waste material collection facilities, “e-waste” and “others” could be seen as one. Moreover, it is to say, that only one sample in the whole survey suggested to use the take back system, to which distributers are obliged by the EAG-VO (BMLFUW, 2017b). It may also be related to the high number of products bought on the internet. Just with the new EAG-VO amendment in 2014, distance selling trade was included to the take back system for distributers. Since then, online distributers must name a legal representation in each country in the EU they sell to, who manage the WEEE take back system for them. But this novation was not communicated very well, which could explain the lack of awareness for the take back systems.

The option for selling the product or passing it on, cannot be considered as a disposing method, because by passing it on the product remains a good. To be considered as waste, the product must fulfill the following criteria. The owner has to dispose the good or has already disposed it or the good has to be collected, stored, transported and treated in public interest (BMLFU, 2017c). So, passing it on or selling it secondhand, the product does not become waste. It enlarges the life span of the product. The option was still given by the survey, as the second-hand market was growing really fast over the last decade. The average second hand consumer does not buy second-hand because of his or her bad financial situation, they use this opportunity because of the larger economic benefit. Especially the market for second hand apparel is growing rapidly, and not only for emerging economies but also on the private sector in developed countries. Additionally, the second-hand market gets more and more professional, which lowers the risk for the consumer and increases the transshipment rate. (Forbes, 2017). Moreover, companies as ebay or willhaben made it possible to shop second-hand online and the usage for online shopping increased from 10.9% in 2003 up to 61.6% in the first quarter of 2017 in Austria (Statista, 2017b).

The same applies to the option of “old cloth collection”. With respect to LED apparel nearly 62% would use the opportunity of an old cloth collection. This may be an ideal behavior of the consumer, as it increases the life span of the apparel, but it also has to be considered, that the electronic equipment has to be removed first. Ideally, people would separate the LED apparel and dispose the electronic part in the e-waste and give the textile part a second chance.

Dealing with the topic of life span and place of retail, the survey revealed that half of the consumer would use their product for more than one year. 21% would only use it for less than half a year and 14% between seven and twelve months. 13% of the sample would use it only once. The difference in the service life can be explained by the different characters of the products. The author assumes, that decoration and apparel are more likely to be used for a longer time, than toys and accessorize. Children’s toys might get obsolete earlier because they may out grow them very fast as they get older. Products of the category accessorize seem to be more a kind of fun gadget for a special event than something being used as a daily good. As there exists no relevant data to the topic above, these are only the assumptions of the author.

Continuing with retail behavior 35% said they bought their LEDs at local retailers. 43% bought online and the rest (21%) didn’t know where their product come from, as they got it as a gift. So, if the gift section is spread in the ratio of online and local retail as the product has to be bought somewhere, online shopping reaches nearly 55%. This correlates with the phenomena of uprising usage of online shopping mentioned above.

Another interesting thing is, that only one sample, mentioned a second-hand online purchase. Regarding the fact, of a growing second-hand online market, it may have been reasonable to mention this option in the survey specifically. It is possible, that parts of the online purchased goods were bought second-hand but with the gathered data, this cannot be verified.

Figure 14 visualizes the interdependency between age and the number of LED products in households. It states clear, that by increasing age, the amount of LED gadgets decreases, from 5 items in mean under the age of 18 to 2 products in the group of over 60 years old. The only outlier is in the group of 25-29 years. So, the main consumer is under the age of 29 as the sample under 29 owns more than half of all investigated LED products. In a next step, the relation between the amount of LED products and the level of education was prepared. Figure 13 shows the result. Again, an indirect relation between these two factors can be drawn. With an increasing level of education, the quantity of LED gadgets decreases. Again, there is an outlier with the sample of college graduates, but a clear tendency cannot be denied. Thus, the typical owner has graduated from compulsory school, apprenticeship or vocational middle school. These three groups own more than half of the investigated LED products. To complete the picture of the typical consumer of the investigated LED gadget, it has to be said, that men own in mean nearly double the quantity, than women. Men own in mean 4.3 in contrast to women with only 2.2 LED items. Moreover, people in rural areas own more than the double amount of LED products compared to residents of urban areas.

So, the estimated typical consumer is male, under 29 years old, has graduated from vocational middle school or lower. He lives in a household with 2-4 persons (in mean 2.88 persons) in a rural area of Austria.

Furthermore, the survey deals with the difference in disposal habits for rural and urban regions. Figure 17 shows the results. It is clear to see, that people in rural areas are more likely to use separate collection such as plastic waste, old cloth collection and e-waste, than people living in cities. This may occur from the anonymity in the urban regions, where wrong disposal behavior cannot be tracked down to the perpetrator. On the other side, in rural areas, the density of door to door collection is much higher and a misbehavior can easily be revealed, moreover as some communities make controls on wrong disposal behavior directly at the household.

A further relation, this paper looks at is between level of education and the disposal behavior of the people. As there is a clear relation between education and quantity, the author assumes, that there is a relation between these two other factors as well. Therefor the disposal behavior was analyzed for every level of education. Figure 15 shows how the disposal behavior changes over the different states of education. However, there is no clear evidence for a relation between these two variables obvious. There may be an interaction between “residual waste” and “e-waste” but there is no evidence for an increasing misbehavior, with respect to disposal, by a decreasing level of education. So, it can be stated, that the level of education has no impact on the disposal behavior. Figure 16 shows the results for a possible relation between age and disposal behavior. The hypothesis was that younger people are more likely aware of using the correct way of disposal, than older ones, as the topic of recycling may be more common to a younger generation. But the result shows, that there is no clear relation. As the people get older, they tend to use the residual waste option until the age of 39. From the age of 40 this behavior decreases rapidly. In contrast, the application of e-waste decreases rapidly towards the age of 39, but increases afterwards. Thus, there is a clear distinction between age and disposal behavior, but there is no clear legitimacy.

5.2 The material structure of the investigated LED products

As mentioned before, to react on new waste streams on time, it is necessary to become aware of them and to ascertain their waste management relevance. With knowledge about, the mass, the volume, the hazardous potential, the environmental impact, the resource demand and the consumer behavior, possible threats can be identified and countermeasure can be taken. This conforms with the precautionary principle, a guideline in the European environmental policy. It says, that even if there is not enough scientific evidence for a threat, security measures have to be taken to prevent possible future threats (BMLFUW, 2017a). If the threats can be found not only countermeasures for the end of life phase should be implemented, but according to the precautionary principal the industry should be challenged to move forward to a more sustainable product (Lim et al., 2011). To assess the waste management potential of LED products with neither primary lighting function nor any technical signaling function, four representative products have been chosen and dissembled.

5.2.1 The selected products

As there is no data which product exactly has the highest sales, the author chose four out of his personal empirical experience, which seem to be on the market for a longer time. For apparel the choice were lighting shoes, as they are on the market for ages and are still very popular. For accessorize LED shoe laces have been chosen, as they are a top seller regarding to some online shops. In the category of decoration, lighting Christmas decoration was picked as seasonal decoration is a top seller. For toys, a toy car with mounted LEDs is used as it is common for children’s toys for years. Figure 18 shows the four products and table 8 provides the technical data.

The four products, got dismantled and analyzed. The decoration is equipped with one 5mm pin type LED and powered by one CR2032 button cell. The whole construction, is very simple. The product just uses one switch, a LED and a button cell. In contrast, the toy car uses a lot more technique, as it also has a speaker. It uses one yellow surface mounted LED and two AAA batteries for power supply. Moreover, it has a printed circuit board.

With respect to apparel, the LED lighting shoes, have the highest number of LEDs. The shoes use 18 white surface mounted LEDs for each shoe and is powered by a lithium ion accumulator, which can be charged by USB. Another product is a pair of LED lighten shoelaces. They use two 5mm pin type red LEDs each and are powered by one CR2032 button cell each. Furthermore, the luminous intensity for each type of LED was measured to categorize them in high and low intensity LEDs, as they have a different resource demand. According to LIM et al. (2011) all these LEDs can be classified as low intensity LED.

Figure 18: the four selected products and their electronic components

	Accessorize	Decoration	Apparel	Toys
Weight (total) [g]	34	69	197	111
Weight (e-components) [g]	8.36	6.03	34.76	41.61
Weight (housing)	25.64	62.97	162.24	69.39
Type of LED	5mm pin type	5mm pin type	Surface mounted	Surface mounted
Color of LEDs	Red	red	white	yellow
Number of LED	2x 2	1	18	1
Type of accumulator	2x CR2032	CR2032	Lithium ion accumulator	2x AAA

Table 8: relevant data of the four products

With the information given in table 8 and the data provided by Lim et al. (2011) calculations were made to get the approximately resource demand of the electrical components. For the calculation the weight of a single 5mm pin type LED was assumed with 0.21 grams. Although, half of the products use surface mounted LEDs, only for 5mm pin type LEDs composition data exists. For this reason, all calculations are based on 5mm pin type LEDs. Moreover, the resource demand for surface mounted LED is higher (Lim et al., 2011). Further on, the hazardous potential for each product group can be evaluated and transferred for the complete waste stream. Table 9 deals with the resource demand of the used LED technique. As described in chapter 4.3 copper, nickel, iron, silver and gold are the most relevant materials for their weight and/or their environmental impact. Therefor only these materials are considered. The resource demand for wiring and printed circuit boards was not considered.

	Accessorize	Decoration	Apparel	Toys
Copper [mg]	0.07	0.02	0.24	0.2
Nickel [mg]	4.03	1.01	30.87	0.32
Iron [mg]	239.87	59.97	2353.45	63.19
Silver [mg]	0.36	0.09	3.93	0.05
Gold [mg]	0.03	0.01	0.88	0.01

Table 9: metal content of the four Products according to Lim et al. (2011)

5.2.2 The mass of the potential waste stream

Combining the total weight with the amount of investigated LED products in Austrian households the overall potential mass of the waste stream can be roughly assessed. It has to be note, that for the actual waste stream calculations, products getting into the old cloth collection or being sold/ passed on have to be removed, as they are not getting waste per definition right now. Moreover, with the gathered data the mass for each disposing opportunity is calculated. Hence, the material loss can be seen, at waste streams, which do not end up in e-waste. Table 10 shows the mass of the waste stream, regarding to the weight of the whole item and the weight of only electronic components.

Min Max Mean	Accessorize [kg]	Decoration [kg]	Apparel [kg]	Toys [kg]	Total [t]
Mass by product weight	56 074	178 167	177 2178	227 444	**639**
	124 042	375 875	403 662	488 173	**1 392**
	90 058	277 021	290 440	357 809	**1 015**
Mass by electronic component weight	26 388	15 570	31 269	85 261	**158**
	58 373	32 848	71 225	182 999	**345**
	42 380	24 209	51 247	134 130	**252**

Table 10: Total mass of the investigated products in Austrian households

	Minimum [kg]	Maximum [kg]	Mean [kg]
Copper	0.8	1.7	1.3
Nickel	37.7	84.9	61.3
Iron	2 797	6 302	4 550
Silver	4.5	10,1	7.3
Gold	0.9	2	1.4

Table 11: total mass of Copper, Nickel, Iron, Silver and Gold over all four product groups

The total weight of the investigated products is between 639 tons minimum and 1 392 tons maximum. The total weight of the electronic components in these products is between 158 tons and 345 tons. Further on the mass of the five metals were calculated.

The results can be seen in table 11. It must be noted, that only the metal consumption of the LED is considered, not the resource demand of the whole electric component.

Table 11 shows, that the metal with biggest share is iron with an approximate weight between 2797kg and 6302kg. Further on, proportionally nickel and silver come in note able quantities, whereas gold and copper only come in small quantities.

The calculation continuous with the mass reaching each of the disposal options. The following calculation, were made with mean figures. Further, the category "other" was taken into account by the category e-waste, as nearly every suggestion would end up in e-waste. The category plastic and old cloth collection were split. The result is in table 12.

	residual waste	e-waste	plastic waste	passing on or sale	old cloth collection
Total [t]	**409**	**380**	**73**	281	180

Table 12: mass reaching each disposal opportunity

The results show, that the biggest share of the total mass ends up in the residual waste, followed by e-waste. Passing on or sale and old cloth collection can be excluded as products ending in these categories are not getting waste in the formal way, as they will be reused.

In a further step, the resources in every disposing opportunity were calculated. Table 13 shows the metal content for each disposing opportunity.

	residual waste	e-waste	plastic waste	passing on or sale	old cloth collection
Copper [kg]	0.3	0.5	0.07	0.3	0.2
Nickel [kg]	12.5	38	0.7	8	28
Iron [kg]	890	2 862	52	619	2 146
Silver [kg]	58	44	0.7	7	3.6
Gold [kg]	0.23	1	0.01	0.18	0.8

Table 13: metal content of each disposal category in kg

6. Discussion and Conclusion

In the past mistakes in waste management and with respect to further environmental issues have been made, partly out of ignorance and partly because of a lack of knowledge and experience. Today's society has the experience of the past and the technology of the future to ascertain, that decisions will be made in a sustainable way. For this reason, new upcoming waste streams have to be considered in time, to take sustainable economic as well as environmental actions.

Light emitting diodes, are in the purview of the EAGVO, the Austrian implementation of the WEEE directive, but only as retro fit LEDs, lighting hoes, USB-LEDs and LED headlights. There is also mentioned a shower head with LEDs, which does not count, as it cannot be found in any of the categories of the EAGVO. It should be mentioned, that this new product category will be discussed in 2018 by the BMLFUW. No further information was found regarding this product. This shower head fits perfectly to the investigated products, as it fulfills every part of the definition. The author assumes, that none of the investigated products is ascertain for its LEDs. Some of them may fit in other categories of the WEEE directive or EAGVO, for example in "Toys, leisure and sports equipment" but the issue of uprising LED applications is not considered.

As mentioned in chapter 4.1 the LED market volume increased rapidly from one billion Euro in 2011 up to approximated 14 billion Euro in 2020. Even tough, the market grows that fast, there is nearly no scientific data available about the environmental impact LEDs have. Moreover, it has to be noticed, that there was communication from authorities, producers or retailers. Every letter of request stayed unanswered. There are lots of papers dealing with application possibilities but only one paper was found dealing with the topic of an environmental threat and resource depletion caused by LEDs. This study by Lim et al. (2011) just deals with the impact of 5mm pin type LEDs, but also mentions, that the usage of surface mounted LEDs is growing. Surface mounted LEDs are assumed to need more material input, than 5mm pin type LEDs. For this reason, the results regarding the metal content of the investigated LED products should be considered as conservative. Sticking with the metal content, Lim et al. (2011) found out, that gold and silver used in LEDs can lead to potential resource shortfalls. Gold is used because of its very low thermal and electrical resistivity. Even the gold content of the total mass of all investigated products is between 0.9kg and 2kg, LEDs contain more gold per kilogram than the average mined gold ore, where the content is about 5mg/kg. Compared to table 4 in Chapter 4.3, LEDs contain between 30.5mg/kg for yellow low intensity up to 176mg/kg for high intensity green LEDs. For that reason, LEDs have a huge urban mining potential. But more over Lim et al. (2011) recommend to adopt the production process in a resource efficient way. The second metal which could lead to supply shortfall is silver. It is used as reflector at the LED chip. The total amount of silver used in all investigated LED products is between 4.5kg and 10.1kg. The Gold and Silver content do not seem high but it is still notable, considering, that these four product groups are just a marginal note of the uprising LED market.

Table 14 shows a comparison of the WEEE waste streams collected in 2014 in Austria and the volume of the approximated waste stream caused by the investigated LED products. As mentioned in bevore, only the three options "e-waste", "residual waste" and “plastic-waste” are considered, as by “passing on or selling” the product or handing it over to the old cloth collection the product still remains a good and does not become waste per definition. It can be seen, that if all of the investigated LED products, which end up in waste are taken together, that the full waste stream is just 1.11% of the collected WEEE in 2014. Moreover, if only the part which ends up in e-waste is taken into account the figure drops down to 0.49%.

Large applications [t]	Freezers [t]	Visual display units [t]	Small applications [t]	Lamps [t]	**Total Waste stream** [t]	Waste stream of investigated LED products [t]	Investigated LED products ending up in e-waste [t]
19 194	11 831	15 415	30 393	892	**77 725**	861	380

Table 14: volume of collected WEEE in Austria in 2014 compared to the approximated waste stream of investigated LED products

Regarding its volume, the waste stream of LED products with no lighting function and neither technical signaling can be considered very small and currently nearly of no relevance. However, the hazardous potential has to be taken into account. Lim et al. (2011) provided the only scientific data covering this topic. The study used standardized leachability tests to find out if LEDs have to be classified as hazardous waste, regarding to US federal and California state regulations. The hazardous waste potential is given for all LEDs, regarding the thresholds of California state regulation, except for low intensity yellow. All other LEDs exceed the thresholds for silver, nickel, copper and lead. Moreover, the batteries used in these products should be mentioned. All three types of batteries, which are used should be collected separately as they all have hazardous potential.

For the whole waste management potential, the life time of the products have to be considered. The time between the product getting on the market and getting obsolete is essential. This time shows the reaction rate, from changes on the market to effects on the waste stream. Knowing the life time of the product, gives waste management the opportunity to react in a proper way (Dehoust et al., 2016). The survey found out, that more than half of the consumers (52%) would use their products longer than one year. The rest assumed to dispose the investigated LED products earlier. 14% would use them between six and twelve months and 21% keep them for up to six months. Precarious is the fact, that 13% of the products are only used once. These figures mean, that nearly 48%, in mean 487 tons, get obsolete in under a year and thereof 140 tons are only used once. As the survey did not ask for the life span of each single product category, it is not possible to figure out which products get used how long and therefor which mass and which materials reach the waste stream in which time. The data should be seen as approximate value.

Overall the upcoming waste stream of LED products with no lighting function and neither technical signaling can be considered as quite small proportional to other WEEE waste streams, as it is very special. However, most of the LEDs have to be considered as hazardous. Furthermore, light emitting diodes are used more and more and therefor special attention should be payed, on waste streams containing a high amount of LEDs. Moreover, the approximated life span of the investigated products is not very long and supposed to get shorter as the overall life span of electronic goods is decreasing.

What should be also taken into account, is the fact, that people are more likely to dispose small electronic products in the residual waste, than in e-waste. For this study, this means an approximated loss of 0.3kg of copper, 12.5kg nickel, 890kg Iron, 58kg of silver and 0.2kg of gold, only considering the material input of LEDs. Again, this seems not to be a lot but regarding the fact that this waste stream is only half a percent of the total WEEE collection the resource loss can divined. In comparison, according to Rotter et al. (2006) the part of small WEEE in residual household waste is about 0.8% of the annual household’s waste. This is 2.6 kg per inhabitant per year. According to another study from the Netherlands (Huisman et al., 2012) 26% of all small WEEE application end up in the residual waste. Even if Austria has one of the most developed separate collection systems, efforts should be made to create people awareness for the right disposal of small WEEE. As the survey indicate that the wrong disposal behavior prevails in urban regions, measures have to be taken, to gain easier access to a separate collection of small WEEE in cities.

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Appendix 1

Erhebung der abfallwirtschaftlichen Relevanz von LED-Produkten, welche keinem Beleuchtungszweck bzw. keiner technisch relevanten Signalgebung dienen

Seite 1

Sehr geehrte Damen und Herren,

im Zuge meiner Diplomarbeit, an der Universität für Bodenkultur, am Institut für Abfallwirtschaft bitte ich Sie um Ihre Mitwirkung bei der Mengenerhebung von LED Produkten ohne Beleuchtungszweck beziehungsweise technisch relevanter Signalgebung in österreichischen Haushalten. Dabei handelt es sich um Produkte wie leuchtende T-Shirts, blinkende Turnschuhe oder blinkende Eiswürfel.

Umfragedauer ca. 5 Minuten

ACHTUNG: Am Ende der Umfrage können sie an der Verlosung eines 50€ Amazon Gutscheins teilnehmen! Ihre Antworten bleiben weiterhin Anonym!

Die gesuchten Produkte in ihrem Haushalt müssen für die Erhebung folgende Kriterien erfüllen:

1. besitzt mindestens eine leuchtende LED.
2. dient der Dekoration, als Accessoire, Kleidungsstück oder ist eindeutig ein Spielzeug etc.
3. kann seine eigentliche Funktion auch ohne LED erfüllen.
4. hat **keinen** eigentlichen Beleuchtungszweck.
5. die LED ersetzt **keinen** bisher genutzten, herkömmlichen Leuchtmittel.
6. die Funktion der LED gibt **keinen** Information über den Ladezustand.
7. die Funktion der LED dient **nicht** primär der Sicherheit des Nutzers (z.B.: leuchtendes Armband zum laufen).

Seite 2

Wie viele Produkte befinden sich derzeit in Ihrem Haushalt und entsprechen der vorher genannten Definition? *

Das gesuchte Produkt muss folgende Kriterien erfüllen:
1. besitzt mindestens eine leuchtende LED.
2. dient der Dekoration, als Accessoire, Kleidungsstück oder ist eindeutig ein Spielzeug etc.
3. kann seine eigentliche Funktion auch ohne LED erfüllen.
4. hat **keinen** eigentlichen Beleuchtungszweck.
5. die LED ersetzt **keinen** bisher genutzten, herkömmlichen Leuchtmittel.
6. die Funktion der LED gibt **keinen** Information über den Ladezustand.
7. die Funktion der LED dient **nicht** primär der Sicherheit des Nutzers (z.B.: leuchtendes Armband zum laufen).

- ○ Keines
- ○ 1-3
- ○ 4-6
- ○ 7-9
- ○ 10-15
- ○ 16-20
- ○ mehr als 20

Seite 3

Wie viele davon sind Accessoire/ Wareables, aber keine eigentlichen Kleidungsstücke (z.B.: Schmuck, Armbänder, Gürtel, Schuhbänder, Brillen, Kappen etc.)?

- ○ keines
- ○ 1-3
- ○ 4-6
- ○ 7-9
- ○ 10 oder mehr

Seite 4

Wie viele davon sind Kleidungsstücke (z.B.: T-Shirt, Pullover, Schuhe, etc)?

- ◯ keines
- ◯ 1-3
- ◯ 4-6
- ◯ 7-9
- ◯ 10 oder mehr

Seite 5

Wie viele davon sind Dekoration (z.B.: Bilderrahmen, Blumen, Untersetzer, etc)?

- ◯ keines
- ◯ 1-3
- ◯ 4-6
- ◯ 7-9
- ◯ 10 oder mehr

Seite 6

Wie viele davon sind Spielzeug?

- ◯ keines
- ◯ 1-3
- ◯ 4-6
- ◯ 7-9
- ◯ 10 oder mehr

Seite 7

Wo würden Sie Accessoires/ Wareables entsorgen

Bitte beantworten Sie diese Frage auch, wenn Sie das genannte Produkt nicht besitzen!

- ◯ Restmülltonne
- ◯ Elektroschrott
- ◯ Kunststofftonne
- ◯ Verkauf bzw. Weitergabe
- ◯ Sonstiges: [ ]

Seite 8

Wo würden Sie ihre Dekoration entsorgen

Bitte beantworten Sie diese Frage auch, wenn Sie das genannte Produkt nicht besitzen!

- ◯ Restmülltonne
- ◯ Elektroschrott
- ◯ Kunststofftonne
- ◯ Verkauf bzw. Weitergabe
- ◯ Sonstiges [ ]

Seite 9

Wo würden Sie Kleidungsstücke entsorgen?

Bitte beantworten Sie diese Frage auch, wenn Sie das genannte Produkt nicht besitzen!

- ◯ Restmülltonne
- ◯ Elektroschrott
- ◯ Altkleidersammlung
- ◯ Verkauf bzw. Weitergabe
- ◯ Sonstiges: [ ]

Seite 10

Wo würden Sie Spielzeug entsorgen?

Bitte beantworten Sie diese Frage auch, wenn Sie das genannte Produkt nicht besitzen!

- ◯ Restmülltonne
- ◯ Elektroschrott
- ◯ Kunststofftonne
- ◯ Verkauf bzw. Weitergabe
- ◯ Sonstiges: ____________

Seite 11

Wie haben Sie diese Produkt erworben?

- ☐ Online
- ☐ Einzelhandel
- ☐ Geschenk
- ☐ Sonstiges: ____________

Seite 12

Wie lange schätzen Sie, werden Sie dieses Produkt, gerechnet seit dem Kauf bzw. seit Sie es geschenkt bekommen haben nutzen?

- ◯ einmalig
- ◯ 1-6 Monate
- ◯ 7-12 Monate
- ◯ länger als ein Jahr

Seite 13

Geschlecht

- ◯ M
- ◯ W

Alter

- ◯ unter 18
- ◯ 18 - 24
- ◯ 25 - 29
- ◯ 30 - 39
- ◯ 40 - 49
- ◯ 50 - 59
- ◯ über 60

Personen in Ihrem Haushalt

- ◯ 1
- ◯ 2-4
- ◯ mehr als 4

höchste abgeschlossene Ausbildung

- ◯ Pflichtschule
- ◯ Lehre
- ◯ Berufsbildende mittlere Schule
- ◯ AHS
- ◯ BHS
- ◯ Hochschulverwandte Lehranstalt
- ◯ Universität, Fachhochschule

Region in der Sie momentan Leben

- ◯ Land
- ◯ Stadt

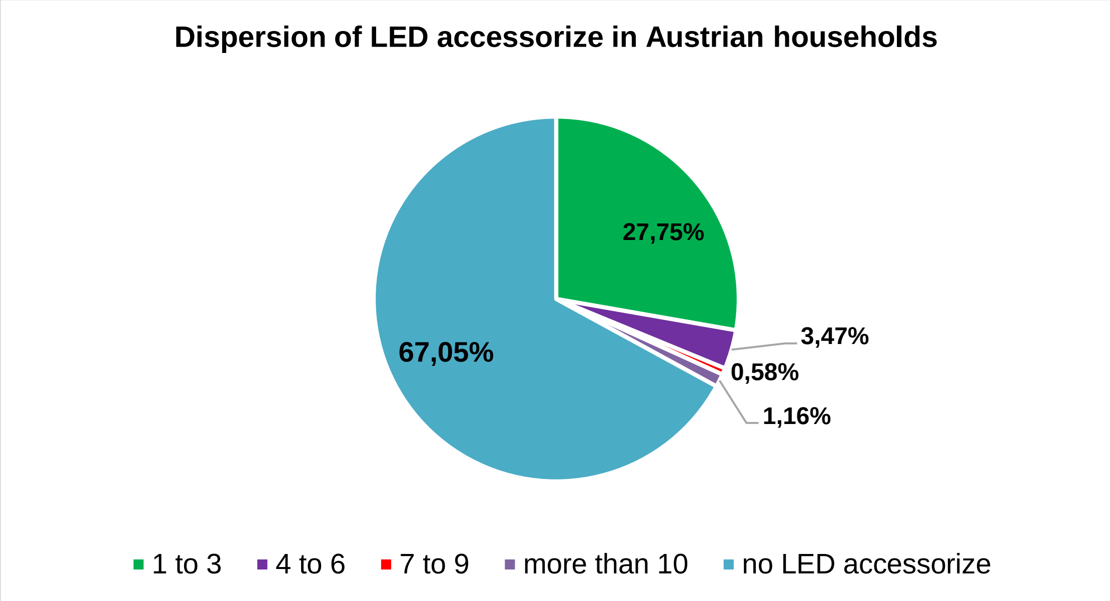
Seite 14

Vielen herzlichen Dank für Ihre Teilnahme.

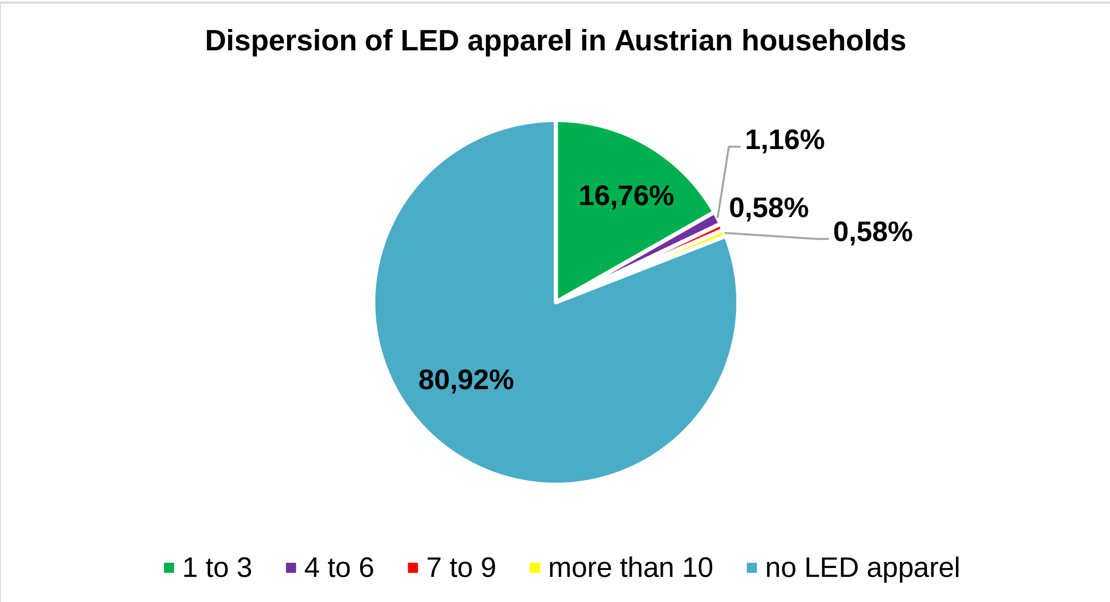
Zur Verlosung!

» Umleitung auf Schlussseite von Umfrage Online

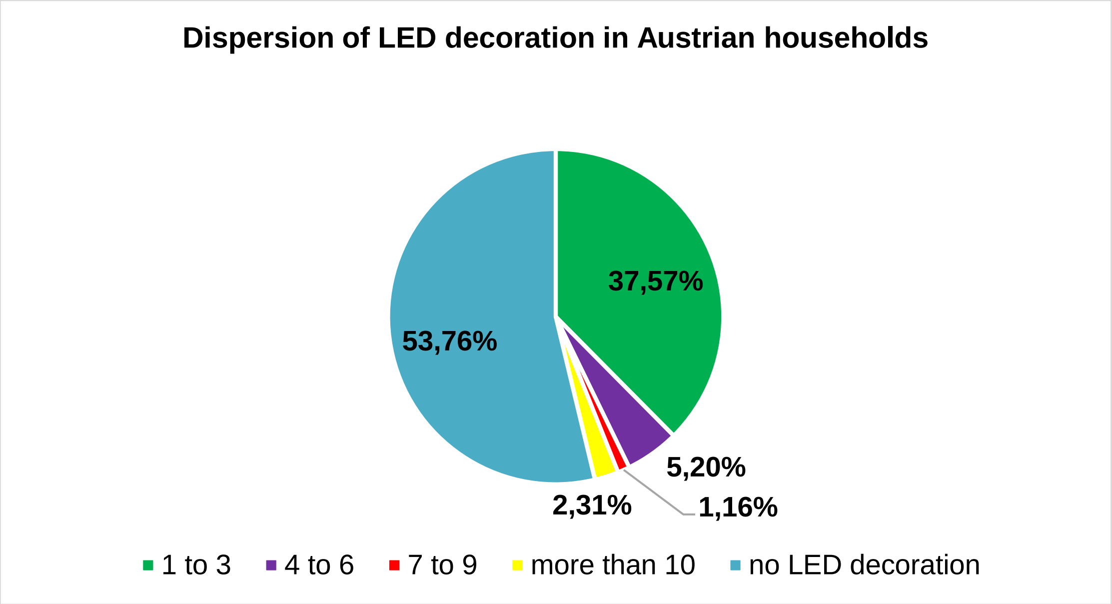
Appendix 2



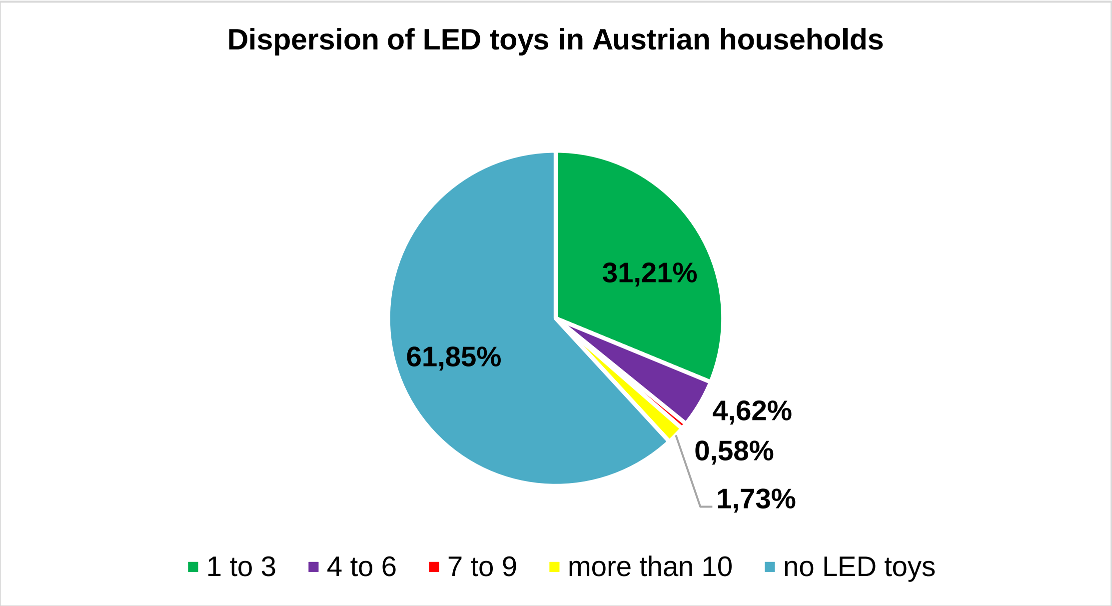
Minimum, maximum and mean number of LED accessorize in Austria	
minimum	3 386 024
maximum	18 277 166
mean	4 508 564



Minimum, maximum and mean number of LED apparel in Austria	
minimum	1 960 329
maximum	10 581 517
mean	2 610 221



Minimum, maximum and mean number of LED decoration in Austria	
minimum	4 752 314
maximum	25 652 163
mean	6 327 809



Minimum, maximum and mean number of LED toys in Austria	
minimum	3 920 659
maximum	21 163 035
mean	5 220 443