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ILLEGAL DUMPING OF END-OF-LIFE VEHICLE WASTE IN THE FOREST AREA NEAR KAUNAS CITY

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When end-of-life vehicles (ELV) are not properly managed, they can cause environmental problems and loss of millions of tonnes of materials. If metals (steel, aluminium, copper) are effectively separated and utilised, only small amounts of ELV plastic waste is recycled. Study showed that local car dismantlers still try to get rid of ELV waste which has a negative market value by illegally dumping them in secluded places of natural environment. Main category composition of illegally disposed ELV waste in the forest area near Kaunas city (Lithuania) was evaluated, with a special focus on a polymer-specific plastic waste identification and separation. Seventeen points of illegal vehicle waste dumping were discovered during one-day visit to the surroundings of the Veršvas Landscape Reserve area (Kaunas City Municipality); in fourteen of which only old tyres were detected which is not necessarily a product of illegal dismantling. Total amount of illegally disposed ELV waste found (excluding tyres) was 124.3 kg: 94.4 % by mass of which was classified as non-hazardous and only fraction of automotive fluids (used engine oil) was categorised as hazardous (95.6 %). The major fraction was automotive plastics – 57.9 % (by mass), the minor – metal fraction (only 0.6 %). The majority (96%) of all discarded ELV waste was combustible and only 3.8 % consisted of non-combustible materials (mainly glass and metals). Incineration of such waste can produce energy with a possibility to recycle the remaining metals. Polymer-based fractionation showed that 82 % of all plastic waste was recyclable (thermoplastic) and only 10 % were thermosets (non-recyclable), but in many cases thermoplastic materials were with polymer fillers which could complicate the recycling process. All plastic waste types were 'synthetic' (derived from crude oil, natural gas or coal); no 'bio-based' polymers (derived from renewable materials or waste biomass) was found. All plastic waste found was 'non-biodegradable' and thus highly persistent in the natural environment.

Keywords: *circular economy; environmental pollution; end-of-life vehicle; waste management; illegal waste dumping; hazardous waste; waste sorting by category; plastic waste identification; plastic waste recycling*

INTRODUCTION

In order to comply with the objectives of a new Waste Framework Directive (WFD) (Directive 2008/98/EC of the European Parliament…, 2008) and move towards a European recycling society with a high level of resource efficiency, Member States shall take measures to promote high quality recycling and shall set up separate collections of waste where technically, environmentally and economically practicable and appropriate to meet the necessary quality standards for the relevant recycling sectors. Among other amendments WFD also introduces a procedure for defining end of-waste (EoW) criteria. It also says that Member States should support the use of recyclates (including recovered metal, paper, glass and plastics), in line with the waste hierarchy and with the aim of a recycling society, and should not support the landfilling or incineration of such recyclates whenever possible.

Due to their slow decomposition rate in natural ecosystems plastic waste is responsible for modern environmental issues. Most plastic ever produced has not been recycled, and end their life either being disposed in landfills or persisting in the environment as plastic pollution. The reuse of plastic reinforces the viewpoint of a circular economy, which has been a universal trend in recent years (Lahtela et al., 2019). Polymer based materials are widely used and the largest application for plastics is as packaging materials, but they are also used in a wide range of other sectors, including construction industry, consumer goods, textile industry and electronics. Thermoplastics can be easily recycled or reprocessed into a secondary material. Worth mentioning, that recycling delays, rather than avoids, final disposal (Geyer et al., 2017).

While end-of-life vehicles (ELV) is one of the major sources of post-consumer waste plastics (Villanueva and Eder, 2014). Every year, over six million vehicles in Europe reach the end of their life and are treated as waste. The Directive on end-of-life vehicles (ELV Directive) (Directive 2000/53/EC of the European Parliament…, 2000) sets clear targets for reuse and recycling of ELVs and their components. When end-of-life vehicles are not properly managed, they can cause environmental problems and the economy loses millions of tonnes of materials. The automotive manufacturing industry is among the largest consumers of primary raw materials, and if metals (steel, aluminium) are effectively separated and utilised, only small amounts of plastics are recycled. Directive on motor vehicles with regard to their reusability, recyclability and recoverability declares that vehicles belonging to category M1 shall be so constructed as to be reusable and/or recyclable to a minimum of 85 % by mass (Directive 2005/64/EC of the European Parliament…, 2005).

According to the data of the state company "Regitra" (The number of vehicles registered…, 2023) during the first 8 months of year 2023 131,232 cars were registered for the first time, of which 75.9 percent were used (second-hand) cars. Meanwhile, new M1 class passenger cars registered during the same period accounted for only 16.4 percent (total number – 117,507). Bearing in mind that the average age of a car is close to 15 years, up to 150 thousand of end-of-life vehicles are generated in Lithuania every year. After disassembling these ELVs, hundreds of thousands of tons of waste are generated, of which about 30 percent consists of plastic, rubber, glass and different composite materials that have low or even negative value in the recycling market, which in the case of illegal dismantling end up without recycling either in the municipal waste containers, or even worse – in remote places of our environment. Thus, environmental pollution reduction, proper waste collection, reuse and recycling are extremely relevant topics when it comes to waste management of end-of-life vehicles.

Aim of this study was to analyse and evaluate the main category composition and recycling possibilities of illegally disposed ELV waste, with a special focus on a polymer-specific plastic waste identification, separation and evaluation.

RESEARCH METHODS

Illegally disposed end-of-life vehicle parts (except old tyres) were collected in the surroundings of the Veršvas Landscape Reserve area (Kaunas City Municipality) during a one-day visit in May, 2019. Reserve coordinates: 54.924, 23.857; total reserve area – 108 ha; year of establishment – 1995. It was established seeking to preserve the landscape of the stream Veršvas valley as an integral natural-cultural territorial complex (State service for…, 2023). The investigated reserve area was only near the local roads entering from the city or crossing the reserve territory (Figure 1a, highlighted in red). The observed distance from the road was about 30-50 m.

a **b**

Figure 1. Investigated forest area for illegal ELV dumping: **(a)** map of Veršvas landscape reserve: green line – boundaries of the landscape reserve area; light red road – highway A5 (E67 Via Baltica); dark red highlighter – investigated area near the local roads; **(b)** spots of illegal ELV waste disposal (map (**a**) after: https://saugoma.lt/lt/teritorijos/versvos-krastovaizdzio-draustinis);

Analysis of the type and quantity of ELV waste was performed by manual sorting of illegally disposed vehicle parts according to the criteria of material recyclability. Initially the illegally disposed ELV waste was separated visually into 9 most common waste sorting categories. Seven categories were classified as non-hazardous waste: glass, metal, plastic (divided into automotive plastic and packaging plastic), rubber, textile, wood, while automotive fluids (like transmission fluid, antifreeze, motor oil) were classified as hazardous waste. Finally waste residue left after sorting into 8 categories was defined as “other” category and consisted of waste containing composite materials, also complex vehicle parts difficult to disassemble, as well as unidentified waste materials or identified but not assigned to any of the above mentioned categories. After sorting waste of each of the mentioned categories were weighed using a hand-held scale to the nearest 0.1 kg.

Automotive plastic waste was taken to the laboratory and was further sorted into 12 polymer-based plastic categories. Focus on the low cost, easy to use identification methods was taken. Initially sorting was performed by either finding a numerical code (so called resin identification code – RIC), or polymer-based abbreviation (letter code), which usually consists of the first letters of polymer chemical name: PET – polyethylene terephthalate; PE-HD – polyethylene (high density); PE-LD – polyethylene (low density); PVC – polyvinyl chloride; PP – polypropylene; PS - polystyrene; ABS – acrylonitrile/butadiene/styrene copolymer; PMMA, PM – polymethylmethacrylate; PC – polycarbonate; PA – polyamide; PUR – polyurethane. Numerical RIC code is a number inside the recycling symbol. Recycling image could be a triangle of three chasing arrows, or just an ordinary triangle (Figure 2a). (Lassesson and Romson, 2021). When recycling symbol based RIC code was rarely used for automotive parts marking, letter coding was found on the majority of unbroken plastic parts (Figure 2b, 2c and 2d).

a b c d

Figure 2. Resin identification codes (RIC) with recycling numbers (**a**) of the main types of non-fibre plastics used for mass production: 1 - polyethylene terephthalate (PET or PETE); 2 – high-density polyethylene (HDPE or PE-HD); 3- polyvinyl chloride or vinyl (PVC or V); 4 – low-density polyethylene (LDPE or PE-LD); 5 - polypropylene (PP); 6 - polystyrene (PS); 7 – other (O) or corresponding polymer letter code, like e.g. ABS, PC, PUR, PA, PM, etc.; Examples of the letter codes found on ELV plastic parts: (**b**) – polypropylene (PP); (**c**) – acrylonitrile butadiene styrene (ABS); (**d**) – composite plastic automotive part composed of PP (hard) and thermoplastic elastomer vulcanizate (TPE-V) (soft) materials

In the absence of appropriate plastic marking code (rubbed off, unreadable, broken part with lost code), polymer type of ELV plastics was identified following 3 steps: initially by visual/manual inspection evaluating plastic appearance and physical properties (feeling of hydrophobic surface, evaluating hardness, flexibility, elasticity etc.). Following the density test (Table 1), with a help of which plastics can be roughly divided into two groups: lighter than water (floats in water) and heavier than water (sinks in water) (Lassesson and Romson, 2021). Density of plastics may vary in the wide range of 0.5 to 2.00 g/cm^3. It mainly depends upon the type of polymer, the fillers and the manufacturing process. Foamed plastics will usually float due to the trapped air, while plastic with mineral filler will have a higher density than pure polymer, which means that PE or PP will sink. A salinity-based density separation uses a saturated salt solution to make up the floatation of plastic particles of lower density and separation of plastic particles with higher density by sedimentation. The following salts can be used for density separation: sodium chloride, sodium bromide, and sodium iodide, zinc chloride, zinc bromide, sodium tungstate dihydrate (Campanale et al., 2020; Lambert and Wagner, 2018). During the density test sample should be placed in either in distilled water or salt solution ensuring that no air bubbles are trapped in, on or under the plastic sample.

Table 1. Density of non-fibre and not-foamed plastics (after Campanale et al., 2020)

Polymer (plastic)	RIC (numerical code)	Abbreviation (letter code)	Density, g/cm^3
Polypropylene	5	PP	0.87-0.93
Low density polyethylene	4	LDPE	0.91-0.93
High density polyethylene	2	HDPE	0.94-0.97
Freshwater (dihydrogen monoxide)	-	-	≈1.00
Seawater	-	-	1.025
Polystyrene	6	PS	1.02-1.07
Acrylonitrile butadiene styrene	7 (O)	ABS	1.04-1.06
Polypropylene with fillers	7 (O)	PP + fillers	1.04-1.09
Polymethyl methacrylate	7 (O)	PMMA	1.09-1.18
Polyamide (PA6 and PA66)	7 (O)	PA (PA6 /PA66)	1.12-1.14
Polycarbonate	7 (O)	PC	1.20-1.22
PC+ABS copolymer	7 (O)	PC+ABS	1.19-1.22
Polyurethane	7 (O)	PU	1.20-1.26
Cellulose acetate (or acetyl cellulose)	7 (O)	CA (AC)	1.28
Polyvinylchloride	3	PVC	1.35-1.39
Polyethylene terephthalate	1	PET	1.36-1.40
Polybutylene terephthalate	7 (O)	PBT	1.47-1.49

However, it should be remembered that density of a specific polymer can be changed by additives (especially polymer fillers) used in the production of plastics, which have been found quite often in disposed automotive plastics. Such materials are usually used as mineral fillers, which give the desired mechanical properties - flexibility, strength, hardness, as well as non-flammability, and as a rule increases plastic density. An example can be glass fibre, which was identified by GF letter coding. Density can also change in the case of foamed or aluminized plastics. Density of filled/reinforced polymers can be by 0.1-0.6 points higher to compare with pure polymer.

Final identification step (if needed) was a flame test (Table 2). When identifying plastics (polymers) based on their flame reaction, the following characteristics are evaluated: their flammability (e.g.: burns while melting, extinguishes when removed from the flame, burns hard, does not burn at all, etc.), flame nature (flame colour, smoke formation and colour, combustion sound) and the smell of the combustion products (Lassesson and Romson, 2021). Flame test was performed in a fume hood in a colourless burner flame. Additionally a copper (Cu) wire was used to identify PVC plastics.

Table 2. Identification of polymer-based plastic types by flame test

Name of polymer (plastic)	Flammability	Nature of flame	Odour of combustion products
Polyethylene PE Polypropylene PP	Ignites easily. Melts and releases dripping “firebombs” After removing from the flame continues to burn	Blue flame with a yellow tip. Smoke appears when drops falling	Almost odourless. Weak odour of paraffin (like candle wax)
Polyvinyl chloride PVC (V)	Ignites moderately. Burns but extinguishes when removed from flame. Does not melt – only softens but not releases dripping "firebombs"	Bright yellow flame. A green tip can be observed at the bottom of the flame	Bitter smell of hydrogen chloride
Polymethyl methacrylate (organic glass) PMMA	Burns and makes crackle noises. Does not melt, just softens. Moderate smoke	Pale yellow flame with white flashes. Blue flame bottom	Weak fruity-floral scent
Polystyrene PS	Burns while melting with flying black soot	Yellow-orange flame with sooty, dark smoke	Specific bitter smell of styrene
Polybutadiene (rubber) PB	Slow to ignite and quickly extinguishes when removed from the flame	Yellow-orange colour, with white flashes and sooty, dark smoke	Specific rubbery smell
Polyethylene terephthalate PET	Ignites moderately, but bubbles as it melts	Yellow flame with dark smoke. Flashes when burning	Specific sour (acidic) smell. Smell of burnt sugar
Phenol-formaldehyde resin PFR	Burns weakly, extinguishes when removed from flame but continues to smoulder	A yellow flame. White flashes can appear	Smell of phenol and formaldehyde
Acetyl cellulose AC	Burns instantly with almost no residue	Bright yellow flame with black smoke	The specific smell of celluloid

After plastic sorting to polymer-based categories each of them again was weighed separately using a hand-held scale to the nearest 0.1 kg.

RESEARCH RESULTS AND DISCUSSION

Main category composition of illegally disposed ELV waste in the forest area near Kaunas city (Lithuania) was evaluated, with a special focus on a polymer-specific plastic waste identification and separation. Study showed that local illegal car dismantlers still try to get rid of ELV waste which has a negative market value by illegally dumping them in remote and secluded places of natural environment. Seventeen points of illegal vehicle waste dumping (Figure 1b), were discovered during a one-day visit to the surroundings of the Veršvas Landscape Reserve area (Kaunas City Municipality). In fourteen places only old tyres were found. Tyres are not necessarily a waste product of ELV illegal dismantling so it was not a study object of this research.

Illegally disposed ELV waste that was collected in three different spots (total amount 124.3 kg) was sorted into fractions according material recyclability (Figure 3). Analysis showed that metal fraction with a high market value (some Al tubes, several Cu wires, and various Me-alloy residues) was the smallest by mass – only 0.8 kg (0.6 % from total). Small amount of metal was also found integrated as a constituent component of other plastic parts, which most probably, due to the light weight and low value, dismantlers did not bother to separate, or simply did not notice. Such composite waste was assigned to the OTHER fraction. This fraction of unsorted (other) waste mainly consisted of auto parts composed of different materials that were difficult to dismantle or even impossible to separate (mainly plastic composites with textile, rubber, metal), together with unidentified waste that was not assigned to any of the previously listed categories. Glass fraction (3.1 %) basically consisted of broken car mirrors and door glasses. Other minor (<10 %) fractions was rubber (2.7 %), textile (5.6 %) and wood (6.8 %). Wood fraction was the second biggest waste category but basically consisted of wooden boxes (fruit, vegetable packaging used in supermarkets) in which smaller and broken ELV parts after disassembling were delivered to the illegal disposal spot. Only small amount of wood waste was directly connected with ELV – some of the BMW interior trim parts were made of wood. There was also quite a lot of textile waste, despite the fact that car seats were not discarded at the disposal site. A significant part of the textiles consisted of oiled rags, non-woven textile, old and dirty garage clothes, etc. Though being polymer-based material rubber was listed not within plastics but into a separate fraction. On-site ELV rubber waste was identified as car mats, car doors sealing tapes and strips, sealing gaskets, shock absorber constituents, other small rubber parts, while waste car tyres was not an object of this study. Used engine oil (identified by specific smell and appearance) was also found on the disposal site – total weight together with plastic container was 7 kg (5.6 %). It was assigned to the only one hazardous waste category indicated as AUTO fluids. All other fractions were classified as non-hazardous and made up the majority (94.4 % by mass) of all illegally disposed EVL waste. Packaging plastic (PACK plastic) was listed as a separate waste category (6.2 kg). This waste not directly originated from ELV dismantling and consisted of broken plastic boxes, empty plastic bottles of automotive fluids and cosmetics (could be alternatively listed as hazardous), also packaging from food products and beverages. This study also showed that more than 96% of all discarded ELV waste was combustible and only 3.8 % consisted of non-combustible materials (glass and metals. Such ENTP waste can be incinerated with energy recovery, while metals after incineration can be recycled. However, according to waste management priorities, waste recycling but not incineration is always a more desirable option.

Meanwhile, vehicle interior and exterior decorative as well as structural plastic (AUTO plastic fraction) made up the largest part – 57.9 % (by mass) of all the investigated waste. Despite of being light material with plastic waste density of about 900-1400 kg/m^3, total amount of this fraction was 72 kg.

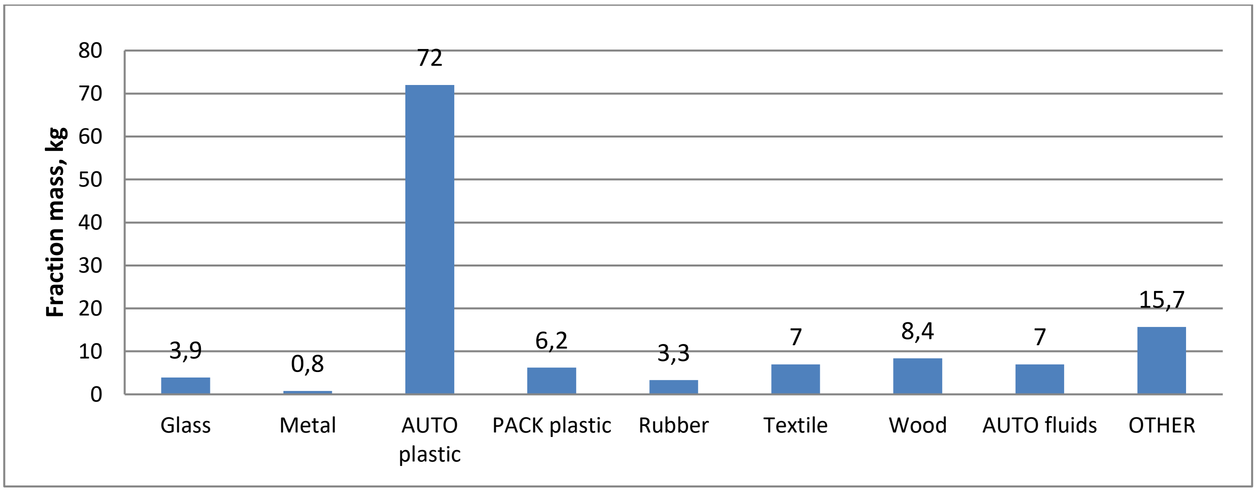

Figure 3. The major recyclable waste fraction distribution of ELV by weight, kg (AUTO plastic – automotive plastic; PACK plastic – packaging plastic; AUTO fluids – automotive fluids) (waste collected at Veršvas Landscape Reserve area, Kaunas city, May 2019)

Further polymer-based sorting of ELV plastic waste showed that the largest part (37 %) of AUTO plastic fraction was made up of the simplest and cheapest polymer-based materials - PP and PE (Figure 4) – total weight was about 26.6 kg (PP – 16.7 kg and PE 9.9 kg respectively). In many cases, these polymers were made with the addition of various fillers (glass fibre, talc, other mineral materials) in order to improve their operational properties, and to reduce their cost. Structural parts, engine and bottom protection, door inner parts, bumpers, fuel tank elements, etc., as a rule, are made from PE and PP plastics. Due to better mechanical properties, high density polyethylene HD-PE was used much more often than low density polyethylene HD-PE. Both PE and PP are light, soft (flexible), capable of moulding (easily survive the temperature and pressure during the moulding process), highly resistant to the effects of the environment and chemicals (British plastics..., 2023). But higher filler content can limit the recycling possibilities of these plastics. Parts containing expanded polypropylene (EPP) were also detected. It is a foamed polypropylene that is used where lightness is required but good mechanical properties are not a priority. Foamed EPP is also widely used for heat and sound insulation. Among other advantages, it is more easily recycled than expanded polystyrene (EPS) (British plastics..., 2023).

Other major plastic fractions were based on ABS copolymer – total amount 21.5 kg (30 %). Due to the different composition and processing as well as recycling technology, ABS (7.8 kg) and ABS/PC (13.7 kg) copolymers were separated. Both ABS and PC polymers are more expensive, but they show higher performance and are widely used in electrical & electronics consumer goods as well as automotive industry. ABS/PC plastic blend of two different polymers is widely used in many applications within automotive industry, where the blend gives a desired performance that is not obtained with a single polymer (Geyer et al., 2017; British plastics..., 2023). Such blend can be recycled back into the same type of products.

Two other types of plastic found in significant quantities were PA (6.2 kg) and PUR (5 kg). Both of these plastics are made from relatively expensive polymers (polyamide and polyurethane) and are used in cars due to their specific physico-chemical properties. Polyamide is extremely strong, with some of its mechanical properties it can compete with metals, and it is also resistant to the effects of the environment and chemicals (fuel, lubricants, etc.). There are different types of PA: e.g. PA66 (or otherwise PA6.6) has an excellent balance of mechanical properties (strength, stiffness, impact resistance) and thermal and chemical resistance. Therefore, PA66 is an excellent candidate to replace the metal. PA66 has better heat and tensile strength than another polyamide polymer, PA6. Also, PA66 has excellent resistance to fuels, greases, most organic solvents, so it is suitable for use in automotive parts that are in contact with such liquids, and are also exposed to high temperatures and mechanical factors (Geyer et al., 2017; British plastics..., 2023). Both PA66 and PA6 were found among ELV, but were listed in the same PA category. Most types of polyamides are thermoplastic and recyclable.

Meanwhile, polyurethane is used to make soft parts with sound and thermal insulation properties. PUR is commonly used in foams for furniture and automotive. After blowing PUR, a soft and elastic material is obtained, which, as shown by this study, was used as a component of car doors, as well as the soft part of car seats, head/neck cushions, and other similar car parts made from extruded polyurethane (EPUR). Extruded (foamed) polyurethane was listed in the same PUR plastic waste category. Both foamed and unfoamed PUR being thermosets are difficult to recycle (Geyer et al., 2017; British plastics..., 2023). It means that they are irreversibly hardened and will decompose instead of melt upon heating.

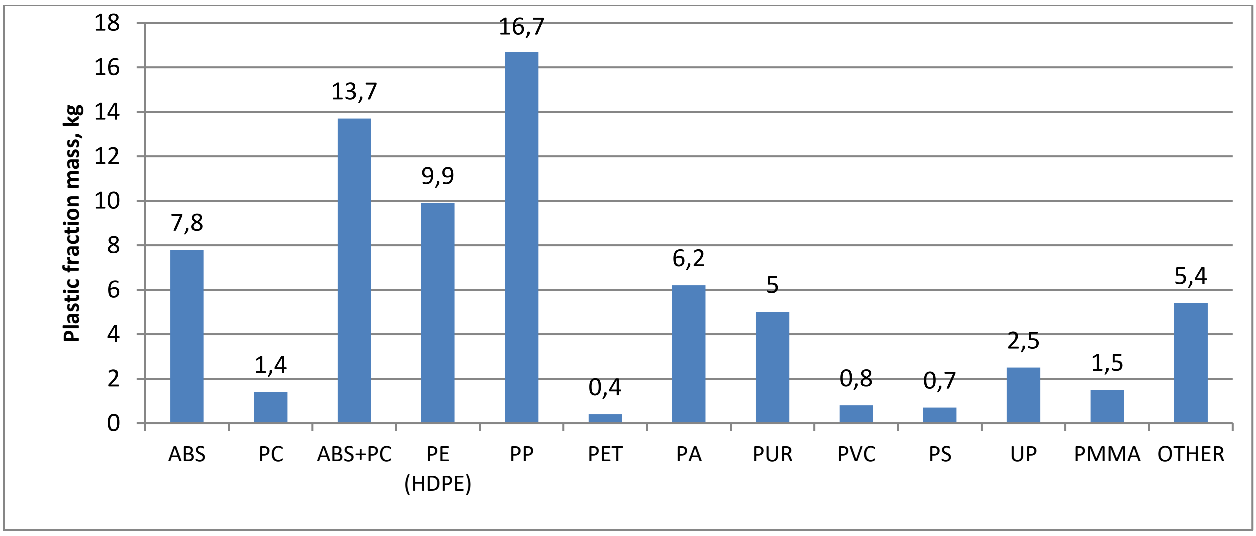

Figure 4. Polymer-based ELV plastic waste fractionation by weight, kg; ABS – acrylonitrile butadiene styrene; PC – polycarbonate; PE – polyethylene; HDPE – high-density polyethylene; PP – polypropylene; PET – polyethylene terephthalate; PA – polyamide; PUR – polyurethane (thermosets); PVC – polyvinyl chloride; PS – polystyrene; UP – unsaturated polyesters (thermosets) ; PMMA – polymethyl methacrylate; (ELV plastic waste collected at Veršvas Landscape Reserve area, Kaunas city, May 2019)

Other types of polymers were less common among ELV waste – polycarbonate and polymethyl methacrylate (1.4 and 1.5 kg respectively). PC and PMMA are both characterized by transparency, excellent optical and specific mechanical properties - they are hard, impact and scratch resistant. They are used for transparent parts of car lights (especially front ones), but light reflectors were made from UP, epoxy or other similar thermoset composites with glass fibre (letter coding GF) as polymer filler.

The amount of other popular plastics (PET, PVC and PS) was very small – total weight only 0.8 kg. PET and PS (together with PE and PP) were the most common between the collected packaging waste (PACK plastic), but these were listed separately (6.2 kg). PS plastic is used less often in automotive industry, because of poor mechanical properties. PVC is widely used in infrastructure and construction industry, but its application in automotive industry is mostly restricted because of its fire hazard – highly toxic emissions at high temperatures. Among other types of plastics, PVC was only identified as an insulating material for car wires – PVC insulation was found as remains of big diameter power cable. Metallic Cu wire was removed as high recyclable value component.

This study gives an idea of what kind of waste illegal dismantlers get rid of first – it mainly consisted of waste materials with a negative market value. Analysis of illegally disposed ELV waste does not reflect the actual ratio of waste materials, as valuable waste components are taken out (e.g. only a few grams of copper wires were found). Also, this study does not reflect the actual ratio of the different types of plastic found in the vehicles – in the investigated disposal spots there were only few car parts containing PU polymers (such as e.g., seats, backrests), and plastic components only of one door were discarded (without metal). It should be also noted that different ratio of polymer-based plastic types will be found in different vehicles. It will depend not only upon a vehicle category (heavy or M1 passenger car), but also upon the specific manufacturer, the year of the production, and will be highly dependent upon the class of a passenger car. More expensive cars (e.g. limousine class), will either contain higher ratio of relatively expensive plastics (ABS, PC, PMMA) as decorative inner parts, or alternatively this plastic will be replaced by other valuable materials, e.g. hardwood. Meanwhile, in cheaper lower-class cars plastics from cheaper polymeric materials as PP, PE will be used.

This study showed that all of the collected waste plastic types were ‘synthetic’ (derived from crude oil, natural gas or coal), and no ‘bio-based’ polymers (derived from renewable materials or waste biomass) was found. Also all plastic waste found was ‘non-biodegradable’ and thus highly persistent in the natural environment.

Polymer-based plastic fractionation showed that 82 % were thermoplastic (recyclable) – through recycling new products can be made, thus saving our planet non-renewable resources. Only 10 % such as PUR, UP polymer based plastics were thermosets (non-recyclable). It also should be noted that in many cases thermoplastic materials were with polymer fillers which could complicate the recycling process.

CONCLUSIONS

1. Total amount of illegally disposed ELV waste at Veršvas landscape reserve area, Kaunas city was 124.3 kg; the major fraction was automotive plastics – 57.9 % (by mass), while the minor – metal fraction (only 0.6 %);
2. 94.4 % by mass of all sorted ELV waste was classified as non-hazardous and only one fraction was categorised as hazardous – total weight of used engine oil (listed as automotive fluids) together with plastic container was 7 kg and made up 5.6 %;
3. More than 96% of all discarded ELV waste was combustible and only 3.8 % consisted of non-combustible materials (glass and metals);
4. All waste plastic types were 'synthetic' (derived from crude oil, natural gas or coal); no 'bio-based' polymers (derived from renewable materials or waste biomass) was found;
5. All plastic waste found was 'non-biodegradable' and thus highly persistent in the natural environment;
6. Polymer-based plastic fractionation showed that 82 % were thermoplastic (recyclable), and only 10 % were thermosets (non-recyclable), but in many cases thermoplastic materials were with polymer fillers which could complicate the recycling process.

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