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Circularity of bulky waste: a case study of krško in Slovenia

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1. *ABSTRACT:* : Since waste is recognized as an excellent alternative for fresh raw materials substitution, the economy and society are striving for efficiently utilization of different waste fractions. Also bulky waste. To increase and accelerate the utilization of bulky waste the Circular Process Model (CPM) has been designed and applied in case study of Krško, Slovenia.

The Material Flow Analysis (MFA) method was used to determine the quality and quantity of bulky waste which can be used at the highest levels of the waste management: 7 % of material was reused for the same or another purpose, 59 % recycled and 34 % energy generated. Besides, the Life Cycle Assessment (LCA) was applied to assess the different processes investigated. The LCA showed recovery has the greatest Global Warming Potential (GWP) impact among almost all of the processes considered.

Using both MFA and LCA demonstrated valuing quality over quantity in bulky waste management can drastically reduce the effects of GWP.

Keywords: *Circular economy, Model, Bulky waste, Material flow analysis, Life cycle assessment*

2. INTRODUCTION

Since the early 1970s onwards, science has been warning policymakers and the rest of the public in lack of fresh raw materials and the need to use alternatives (Ashby, 2021). Recent academic studies have shown significant conservation of virgin materials if the recycled are used. This is also in close connection with reduction of environmental impacts. Meanwhile policymakers adopted many directives (EC, 2018a) and legislative incentives (EC 2012, 2018b, 2020) to accelerate the use of alternative resources and the transition from linear to circular economic flow which embodies strategy for slow, narrow and close resource loops (Bocken et al., 2016).

The concept of a circular economy is illustrated as a closed butterfly diagram, which includes both a technical and a biological part, and presenting the value circle for endlessly fluxing substances (EMF, 2013). Contemporary studies have presented many different definitions of the circular economy or circularity, respectively (Geissdoerfer et al., 2017, 2018; Korhonen et al, 2017; Kirchherr et al., 2017; Merli et al., 2018; Su et al., 2021; Hull et al., 2021; Upadhyay et al., 2021). If we summarize, circular economy aims to rationalize the use of raw materials and energy resources, limit the formation of waste and to ensure the best appropriate waste recovery, with respect to five-step waste hierarchy and waste quality. Despite the good results in theory, we are today in practice still witnessing a number of economic systems using material and energy flows linearly (raw material → product → waste) and destroying biogeochemical processes in the ecosystem. In this context, we can also include the management of bulky waste.

Bulky waste is a technical term taken from waste management to describe waste types that are too large to be accepted by the regular waste collection. It represents a variety of discarded items, e.g. furniture, sporting and children's goods, sanitary elements, mattresses, waste electric and electronic equipment (WEEE) etc., made from different long-lasting materials, e.g. polymers, ceramics, wood, metals etc., that leave the use process at the consumer after a functional or desirability life. The quantities of bulky waste in Slovenia are rising rapidly and have in the year 2019 reached 55,000 tons. Nevertheless, the collection and sorting of bulky waste usually remains unchanged in Slovenia or in the other countries of the European Union (EU).

Bulky waste is generally being collected from the streets or pavements of the area once or twice annually free of charge and sorted in two groups, e.g. hazardous and non hazardous. Regardless of the fact that EU adopted hierarchy of waste management in 2008 (EC, 2008), in practice bulky waste sorting according to quality is usually still neglected. Due to the inconsistent collection and inadequate sorting of bulky waste, large quantities are still being deposited in landfills, illegal dumpings in nature, burned in domestic fireplaces or incinerated without energy production. While the disposal of bulky waste is associated with methane emissions and the occupation of valuable land, the (un)controlled burning of bulky waste, especially wood, may result in pollution of the atmosphere by carcinogenic organic and inorganic aerosols more commonly known as PM10 and PM2,5 (Nava et al., 2015) and increased NOx (Risholm-Sundman & Vestin, 2005; Cichy & Pradzynski, 2007). Furthermore, such inconsistent management leads to carbon loss, which is stored in wood products (Kitek Kuzman & Kuntar). Unfortunately, that does not lead to mitigating climate changes which are mentioned in the EU acts for sustainable or circular development. Due to the fact that the existing methods of bulky waste management do not provide grounds for the circular economy, it is necessary to prepare a suitable model and its environmentally evaluation.

One of the best techniques that has been adopted to assess environmental impacts in circular economy is Life Cycle Assessment (LCA). The LCA is a scientific tool for the methodical and objective evaluation of all the essential influences that a product or a service has on the environment within its life cycle. It is devoted to the comparison of various products with few sequential steps: (1) goal and scope definition, (2) life cycle inventory analysis (LCI), (3) life cycle impact assessment (LCIA), and (4) interpretation, compliant with ISO 14040/44 standards (ISO, 2006a,b).

The observed literature has shown that joining of LCA and circular economy can result in more comprehensive investigation and better understanding of sustainability in waste management, e.g. bulky waste management (Samson-Brek et al., 2019), construction and demolition waste (Zanni et al, 2018; Abouhamad & Abu-Hamd, 2021), tire end-of-life management (Lonca et al., 2018), electric and electronic equipment (André et al., 2019; Jaunich et al., 2020), waste wood cascading (Faraca et al., 2019, Riise et al., 2017). Previusly studies was focused more on the technology of grinding bulky waste using a water jet by the Ecofrag company and assessing environmental impacts applying LCA (Samson- Brek et al., 2019), comparison of global warming potential (GWP) of wood waste management based on quality (Faraca et al., 2019) or establishing holistic framework to systematically estimating life-cycle impacts and costs associated with WEEE management (Jaunich et al., 2020).

Therefore the objective of this contribution is to fill the missing research gaps and present Circular Process Model (CPM) of bulky waste. In this work we will: (1) display waste management processes of bulky waste, (2) investigate material quality, quantity and composition using material flow analysis (MFA), (3) implement environmental assessment employing LCA, (4) perform case study of Krško in Slovenia.

3. METHODS

3.1 Defining the process model and methods for evaluation

The CPM considered: (1) collection orders and appropriateness for reuse, (2) collection and transportation, (3) sorting based on resource quality into different classes, (4) recovery based on resource quality and customer preferences, (5) marketing and sales.

Online bulky waste collection orders 24/7 of waste holders were used. The waste holders provide their personal data, and information about the type of waste, estimated quantity and quality (reusability). Bulky waste was collected using a door-to-door system and transported to recycling centres for all online waste collection orders or else transported by waste holders using their own vehicle.

The goal of sorting all discarded products is to achieve the highest possible quantities taking into account the quality and type of material thus enabling cascading based on the highest possible resource value. In line with the state-of-the art literature, we designed an innovative (cascading) sorting system (Vimpolšek et al., 2022) which follows: (1) primary inspection: classification by quality (excellent, good, average or poor), (2) secondary inspection: classification based on the type of material (furniture, WEEE, sanitary elements, sports and children's goods). Quality and material classification enable work and prolong the lifespan of different discarded products which can store carbon (wood based products), minimize the wastages and improve the sustainability.

Properly sorted material was classified into the appropriate form of recovery: (1) excellent -> preparing for reuse for the same purpose (PRSP), (2) good -> preparing for reuse for another purpose (PRAP), (3) average -> recycling (REC), (4) poor -> energy generation (ENG).

All items collected and repaired were photographed and displayed on company's official website.

Moreover, because there are significant benefits if circular models are also proper evaluated (Mannan & Al-Ghamdi, 2022), the MFA (Brunner & Rechberger, 2004) and the LCA (EC-JRC, 2010) was used. MFA is an analytical method to quantify flows and stocks of materials or substances in a well- defined system. It is an important tool to study the circular economy and to devise material flow management. In this research firstly, bulky waste quantity recording using the MFA method, which represents the material flow through entire waste management, taking into account mass (kg), volume (m3), proportions (%), resource quality, and main material composition (more than 50% – e.g. wood, polymers, metals, etc.) was employed. Mileage of vehicles was also recorded. Secondly, the LCA using ISO methodology (ISO 2006a,b) for evaluating CPM considered was applied. The selected environmental impact was GWP. Modelling was performed in Microsoft Excel ® using Ashby (2021) database. The basis for proper calculation of environmental impacts was performed by the MFA. The combining LCA and MFA allows for both, planning bulky waste management flow and assessing environmental impacts of CPM.

Sorting time or costs were out of the scope. Besides, collection orders, marketing and sales processes were not environmentally evaluated.

3.2 Case study

Case study was performed in Krško, Slovenia during the European Week for Waste Reduction (EWWR 2021) which took place at the public service provider company Kostak between 22 and 26 November 2021. The company carries out the public service of municipal waste collection in municipalities Krško and Kostanjevica na Krki, at 345 km2, supplying 11,000 households and collecting about 11,500 tons of waste annually. It also provides sorting and recovery processes for bulky and other waste streams. The company very well cooperate with Knof social company (so.c.) which is responsible for the realisation of the circular economy in the Posavje and Dolenjska regions with its four Reuse Boutiques. Between 10 and 15 tons of materials, mostly furniture, textiles and electronic equipment, are collected, sold or donated to needy families annually by Knof and Kostak. Processes 1-3 were carried out by the Kostak (also process 4, if the material quality was not well preserved), and processes 4-5 in cooperation with the partner Knof so.c. (see Chapter Defining the process model and methods for its evaluation).

4. RESULTS

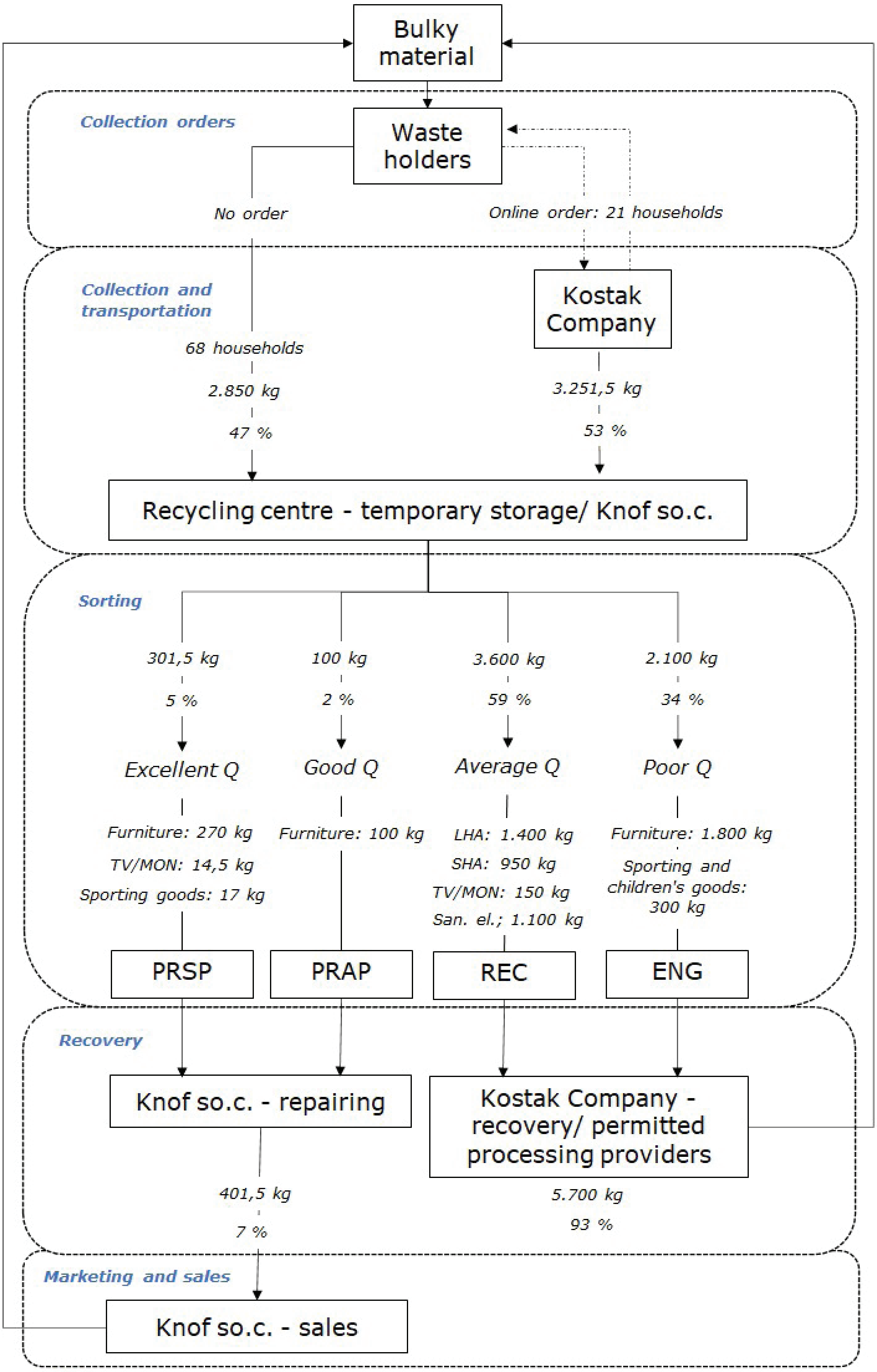
The total amount of collected bulky waste during EWWR 2021 was 71 m3 or 6,101.5 kg. Of that, 36 m3 was transported by Kostak (21 households) and 35 m3 was transported by the waste owners themselves (68 households). Data on weight was gained by weighing and volume by measurement. This was folowed by properly material sorting and classification into the appropriate form of recovery. The material intended for PRSP included mainly excellently preserved types of materials, which were returned to the market after repair and cleaning (301.5 kg of weight and 5.91 m3 of volume) (Fig 1, Fi. 2). To PRAP, we allocated partially damaged and refurbishment needed material (100 kg of weight and of 1.2 m3 of volume). The materials directed for PRAP acquired a different function to their original purpose (Fig. 2, Fig. 3). According to material properties and wishes of our customer preferences (e.g. colour and purpose of use), this was very innovative rework. For REC, the recovered material was of average quality (3,600 kg of weight and 41 m3 of volume) and in ENG material with calorific value, poor quality (2,100 kg, 22.89 m3 of volume), both mechanically damaged and unsuitable for reuse (Fig. 2). The largest amount of material was furniture, followed by LHA, sanitary elements, sporting and childern's goods and TV/MON (Fig. 4a). The main material composition of bulky waste (>50 %) was metal (41 %), followed by wood (35 %), ceramics (18 %) and polymer based products (6 %) (Fig. 4b). All items collected and repaired were photographed and displayed on Knof's official website. The products were sold or donated to assist families in need. CPM and MFA are presented in Fig 2.

Fig. 1: Furniture repairs, Knof so.c.

(a) Preparation of materials

(b) Renovated kitchen chairs

Fig. 2: Circular Process Model and material flow of bulky waste



Notes:

Information flow= ....→ *Material flow=* ——→
Processes boudaries= [dashed box] *TV/MON=televisions and monitors, LHA=large household appliances, SHA=small household appliances*

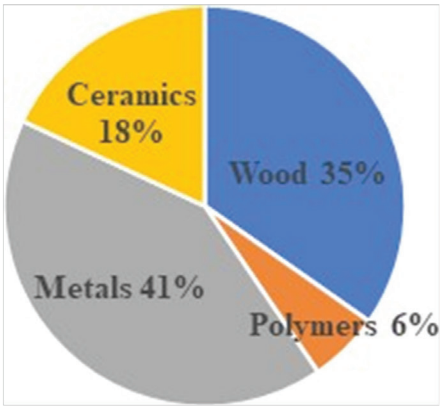
Fig. 3: Materials reused for another purpose at Knof so.c.

(a) The door became a dining table

(b) The bedroom wardrobe became a writing nook

Fig 4: Bulky waste management flow

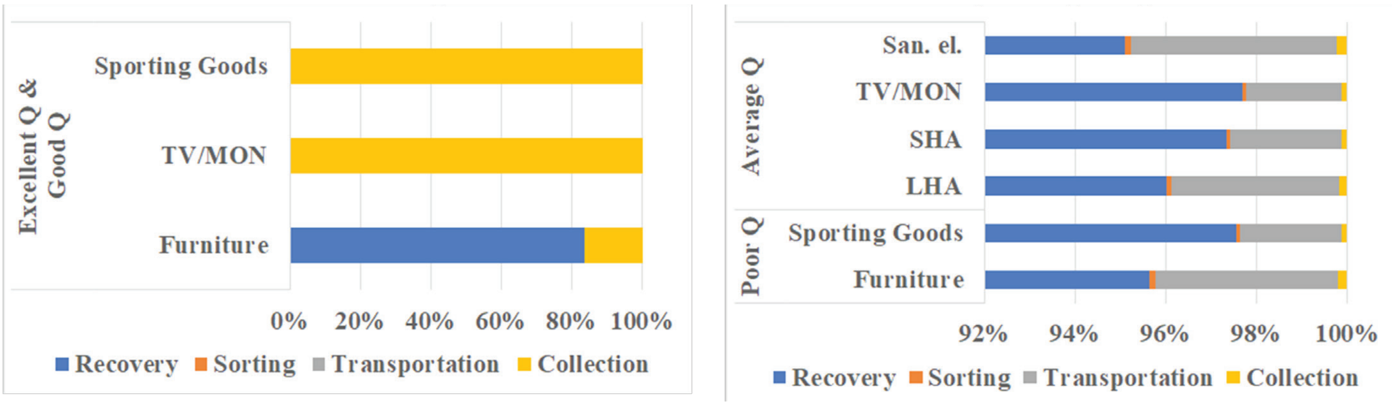
(a) Weight according to quality



(b) Proportions of main material compositions (>50 %)

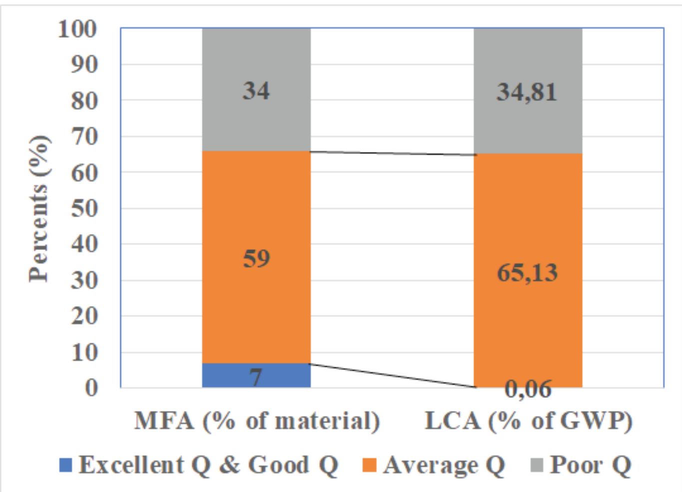
All forms of CPM were environmentally assessed (except collection orders and marketing and sales), namely collection, transportation, sorting and recovery. The selected environmental impact was GWP. Excellent and good quality of material was intended to satisfy PRSP and PRAP. While Sporting goods and TV/MON of this waste flow don't need repairing process, furniture was renovated. Consequently, the impacts of the former on environment is only collection, of the letter is also recovery (renovation). GWP is insignificant in both recovery forms (Fig. 5a). Recovery process in average and poorly perserved material had the greatest impact on the GWP effect: from 95 % for recycling of sanitary elements to 97,7 % for recycling of TV/monitors. This was followed by transportation (2-4 %). Collection and sorting have minor GWP effects on environment (Fig. 5b).

Fig. 5: Environmental impacts of CPM



An insight into the comparison of the recovery process results reveals 7 % of excellent and well preserved bulky waste produce only 0,06 % of total GWP, 34 % of poorly preserved material contribute 34,81 to GWP and 59 % of average preserved bulky waste provide 65,13 % of GWP. Using both MFA and LCA demonstrated excellent and well quality preserved bulky waste intended for reuse can drastically reduce the effect of GWP (Fig. 6).

Fig. 6: Comparison of the results obtained in recovery process based on resource quality



5. CONCLUSION

Due to increasing amounts of waste fractions, waste management is attracting significant attention. Circular economy, which provided for a transition from linear to circular economy flow, is theoretically very well defined, but in practice proper waste management strategies and models are still lacking. Consequently, quality materials are often lost. Public service providers collecting municipal waste do not make sufficient use online collection orders or sorting of the materials based on quality, which accelerates and enables the circularity of materials. Both could also lower the company's operating costs and employ people with disabilities. To this end, CPM that connects and realises the circularity and cascading use of bulky waste materials has been designed. Moreover, the scientific methods MFA, which quantified the material flow in detail, and LCA, which illustrated the effects resulting from processes, have been applied. First, by creating CPM, we have shown that the perception of waste holders is very subjective and that the objective lifespan of material is neglected (physical, functional, technical, etc.). Second, by implementing CPM, MFA and LCA, we wanted to prove that the circularity of material is necessary. A significant amount of material were reused (PRSP & PRAP 7 %) or recycled (REC 59 %) and large amount of primary raw materials were preserved. Bulky waste sorting system also showed valuing quality over quantity can drastically reduce the effects of GWP in recovery process.

Hence, waste hierarchy is completely justified and should be more respected. Finally, we tried to encourage other public service providers and processors to improve their implement of the waste hierarchy and systematic waste management.

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