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Original scientific paper

EXPLORING THE FEASIBILITY OF CONSTRUCTION AND DEMOLITION WASTE RECYCLING IN SKOPJE THROUGH ANALYZING FOUR DIFFERENT SCENARIOS

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A b s t r a c t: Construction and demolition waste (CDW) accounts for 25–30% of the total waste generated in the EU. In North Macedonia, CDW management is primarily based on collection and landfilling by public communal enterprises, with operations not fully aligned with EU standards. CDW generation is estimated at 460,000–500,000 tons/year nationwide and 142,434–154,820 tons/year in Skopje. Four scenarios for CDW treatment in Skopje are proposed: Full Treatment (FT), Selected Treatment (ST), Selected Treatment with Mobile Equipment (STM), and Do Nothing. FT offers high material recovery but requires significant investment and has a 12.2 year ROI. ST has lower costs with over 2 years of execution time, while STM provides the best ROI with a 6 month implementation timeline. All scenarios contribute to reducing GHG emissions (18,031,840 kg CO_2-e) and lowering landfilling by 449,000 tons. Implementation would also yield socio-economic benefits including job creation, improved public awareness, and advancement toward a circular economy.

Key words: construction and demolition waste; collection; landfilling; recycling; scenarios

ИСТРАЖУВАЊЕ НА ИЗВОДЛИВОСТА НА РЕЦИКЛИРАЊЕ ГРАДЕЖЕН ОТПАД И ШУТ ВО СКОПЈЕ ПРЕКУ АНАЛИЗА НА ЧЕТИРИ РАЗЛИЧНИ СЦЕНАРИЈА

А п с т р а к т: Градежниот отпад и шут (ГОШ) сочинува 25–30% од вкупниот отпад генериран во ЕУ. Во Северна Македонија управувањето со ГОШ се базира главно на собирање и депонирање од страна на јавни комунални претпријатија, при што операциите не се целосно усогласени со стандардите на ЕУ. Генерираното количество ГОШ се проценува на 460.000–500.000 тони годишно на национално ниво и 142.434–154.820 тони годишно во Скопје. Предложени се четири сценарија за третман на ГОШ во Скопје: целосен третман (ЦТ), селективен третман (СТ), селективен третман со мобилна опрема (СТМО) и непроменето. ЦТ овозможува висок степен на обновување на материјали, но бара значителни инвестиции и има поврат на инвестиција (ROI) од 12,2 години. СТ има пониски трошоци со повеќе од 2 години за реализација, додека СТМО нуди најдобар ROI и се реализира за 6 месеци. Сите сценарија придонесуваат за намалување на стакленички гасови (18.031.840 kg CO_2-e) и намалување на депонираниот отпад за 449.000 тони. Имплементацијата носи и социо-економски придобивки – отворање работни места, подобрување на јавната свест и премин кон циркуларна економија.

Клучни зборови: градежен отпад и шут; собирање; депонирање; рециклирање; сценарија

1. INTRODUCTION

The Skopje region is located in the northern part of the country and shares a border with Kosovo. Internally, it borders the Polog, Southwest, Vardar, and Northeast regions. The population of the Skopje statistical region according to the 2021 census is 526,502 residents [1]. Skopje is the most populous region in the country even though it is the smallest, covering 7.3% of the total area of the Republic of North Macedonia.

According to the data from the State Statistical Office, the amount of generated municipal waste in the Skopje Region in 2022 was 174,404 tons from which collected were 172,288 tons or around 98.8%. From the total amount of generated municipal waste in the Republic of North Macedonia the collected amount in the Skopje Region was the greatest amounting in 28.4%. In terms of waste types, the largest quantity of collected waste was mixed municipal waste with 81.7%, while the smallest quantity was tire waste with 0.2% of the total collected municipal waste. The average composition of waste in the Skopje Region is given in Table 1. The largest amount of collected municipal waste (99.8%) is disposed of in landfills [2].

T a b l e 1

The average composition of waste in the Skopje Region [3]

Waste type	Amount of municipal waste collected (tons)	Percentage of the total amount of municipal waste collected (%)
Paper	12,178	2.01
Glass	3,754	0.62
Plastics	13,063	2.16
Metal (iron, steel, aluminium)	2,302	0.38
Organic waste (food, leaves, etc.)	40,259	6.65
Textile	8,373	1.38
Tire	1,487	0.25
Mixed municipal waste	494,693	81.68
Other	29,531	4.88

Construction and demolition waste (CDW) represents one of the heaviest and largest waste streams generated in the EU, constituting approximately 25%–30% of the total waste generated [4]. CDW originates from the construction, repair, maintenance, and demolition of infrastructure, buildings, and structures. It consists of construction waste, demolition waste and excavation waste. Construction waste results from management practices on sites, such as surplus materials, sharp and damaged materials. Demolition waste is created from the demolition of existing structures/objects instead of opting for renovation. It often includes many mixed waste streams, which may also contain hazardous substances such as asbestos. And excavation waste typically consists of materials such as soil, excavated earth, and existing foundations removed during excavations for new construction. It may contain contaminated material depending on the previous use of the site [5]. Materials that are commonly included in construction and demolition waste are concrete, bricks, tiles, and ceramics; wood, glass, and plastic; asphalt mixes, tar, and tar products; metals (including their alloys); soil, stone, and excavated material with a backhoe; insulation materials and construction materials containing asbestos; construction materials with gypsum [6].

In the Republic of North Macedonia, the waste management system primarily relies on the collection and landfilling of waste. The services for waste collection, transportation, and landfilling are provided by public communal enterprises (PCEs). Waste disposal is managed by PCEs at the locations of regional municipal landfills. Operations at these locations are carried out on a controlled basis, but they still do not comply with EU requirements [7]. Understanding the management of construction and demolition waste is challenging, with difficulties related to data accuracy and reporting. According to the estimates of the National Waste Management Plan the generation of construction and demolition waste in North Macedonia ranges from 460,000 to 500,000 tons/year, whereas in Skopje ranges from 142,434 to 154,820 tons/year [8]. However, these estimates might be low compared to experiences in other countries. The quantities vary per capita, indicating different reporting methodologies. Estimated quantities in other countries range as follows:

- construction and demolition waste + excavation waste: 2.3 to 5.9 tons per capita annually,
- construction and demolition waste – excavation waste: 0.94 tons per capita annually [9].

Using these figures, the estimated quantity of generated construction and demolition waste in Macedonia (excluding excavation waste) should be around 1.95 million tons per year [8].

There was a planned acquisition of a facility for treatment of construction waste with a planned capacity of 90,000 tons/year. The facility was to receive and treat construction waste. Initially, the CDW was to be crushed, then separated into iron, cement, bricks, and other construction materials so that it can be reused. Part of it was for covering and compacting the layers of the new landfill, and the other part for building roads and similar constructions. The construction of the facility was expected to be completed no later than the end of 2017. However, this activity to this day has not been realized.

2. EXPERIMENTAL

Four scenarios are being considered for further management and treatment of waste from construction activities and construction debris in the Skopje Region. The scenarios developed in this chapter will serve for further analysis and evaluation based on pre-established criteria in the areas of technical and organizational improvement, economic feasibility, and environmental impact and greenhouse gas emissions. The scenarios are divided into two groups: three scenarios (TO DO) and one (DO Nothing) scenario. According to the general activities in the scenario, they are set as follows:

A). **Scenario 1:** *FT – Full Treatment*

A scenario involving automated separation, selection, crushing, and fractionation procedures, additional separation of crushed material (metal, paper, plastic, wood, glass, concrete, and stone aggregates), and creating a final product with high market value. This scenario assumes the establishment of practices that enable the full functionality of the waste management system in the part related to construction waste. Users will be provided with an accessible service for depositing construction waste. Large construction sites, as before, will be responsible for bringing construction waste from construction activities to the Drisla landfill using their own transport machinery. As an additional motivation, the Drisla landfill will offer a low subsidized price for depositing this type of waste, 200 MKD per ton, as opposed to the price of 680 MKD per ton for mixed municipal waste. In this scenario, waste separation and collection practices for construction waste and small reconstructions will be established in two ways.

1) *Micro and very small reconstructions*

For these reconstructions branded bags for construction waste are planned to be used. These branded bags (similar to IKEA's blue bags) with a carrying capacity of up to 50 kg will be sold at various locations in the city and will be available to citizens at a more favorable price. These bags are shown in Figure 1. Craftsmen or small construction firms performing reconstructions will be required to pack the construction waste from the reconstruction in such bags and leave it at the nearest location where the PCEs have containers or bins for waste collection. The disposal of these bags will be done on specified days of the week (different days for different parts of the city), and the location of disposal will need to be reported by phone to the PCEs.

Fig. 1. Bag for packaging CDW

This scenario predicts procurement of a truck for collecting this waste and equipment for loading the bags into the truck. PCEs will establish a collection unit for this waste and a pilot scheme for collecting and transporting waste to the Drisla landfill.

2) *Medium and large reconstructions*

In the case of slightly larger reconstructions where it's not possible to collect construction waste in bags, use of the services of PCEs is planned involving placing a large 5 m³ container for waste disposal. Regarding waste treatment and the technologies envisaged for processing, this scenario proposes a complete treatment up to the production of a finished secondary product. Upon arrival at the Drisla landfill, it is foreseen to have pre-selection (depending on the type of waste) and automated selection of materials. This process involves a moving belt on which the waste is placed, a crusher for waste shredding, magnetic separation for magnetic metals, a blower for lighter waste elements, optical removal of visible waste (glass and plastic), additional crushing, and selection by fractions of different sizes. Equipment for concrete slabs made from secondary materials, separation for cushion material, and separation for tampon material are also part of the envisaged treatment process. The investment value of this scenario is estimated at 1,870,000 euros for equipment, and the necessary procedure for setting up and commissioning the equipment is estimated at 2.5 years (urban and technical technological projects, execution, supervision, and commissioning).

B) **Scenario 2:** *ST – Selected Treatment*

This scenario involves the initial separation of incoming materials by the staff at the Drisla landfill according to previously established procedures. It includes crushing pre-selected material, partially separating parts from crushed material, and creating raw materials. The waste collection processes in this scenario are identical to Scenario 1, i.e., collecting construction debris and waste from smaller reconstructions in designated bags, distributing 5 m³ containers for construction waste from medium reconstructions, and obliging construction firms to bring construction waste directly to the Drisla landfill for larger construction projects. In the waste treatment part, this scenario involves setting up equipment for crushing construction waste on-site at the Drisla landfill. The capacity of the equipment meets the projected annual quotas of generated construction waste for the Skopje Region, amounting to 150,000 tons annually. The value of the equipment is 450,000 euros, and the required procedure for setting up and commissioning the equipment is estimated at 2 years (urban and technical-technological projects, execution, supervision, and commissioning of the system).

C) **Scenario 3**: *STM – Selected Treatment on Mobile Equipment*

This scenario involves preparation for crushing similar to Scenario 2, but with the use of mobile equipment for crushing and final selection (including dust control equipment with sprayers) [9]. This implies that the equipment from the project is used at the Drisla landfill and, if necessary, at other locations designated for processing construction waste (large sites where waste is generated, other regional waste processing centres, construction sites, etc.). This scenario is a combination of the previous scenarios. Methods for collecting construction waste from Scenario 1 are used, indicating complete waste collection. In terms of the final product obtained during waste treatment, products are obtained from Scenario 2, such as cushioning materials and crushed asphalt. Regarding the equipment, this scenario involves the acquisition of mobile construction equipment for crushing construction waste. The capacity of the crusher will be dimensioned to meet at least 50% more than the quantities of generated construction waste in the Skopje Region. This allows the mobile equipment to move at short intervals (transport by truck with a platform) to construction sites or other locations where construction waste is generated. Along with the crusher, elements for preventing dust formation, such as water sprayers, need to be taken. The investment for the equipment in this scenario is 380,000 euros, and the duration for putting the equipment into operation is estimated at 2–3 months from the moment of procurement.

D) **Scenario 0:** *DN – Do Nothing*

A scenario in which the state of handling and managing construction waste remains unchanged. The description of the current situation is given in the Aims and Background section.

1) *Economic analysis of the projected scenarios*

The economic analysis of implementing each scenario is conducted to compare the developed scenarios in this study. The economic analysis is done for a six-year period and is based on several elements:

- The amount of investment required for each proposed technology in the scenarios.
- Funds obtained from the charged subsidized fee for depositing selected construction waste.
- Costs for processing the applied construction waste.
- The value of the material obtained from recycling and processing (as an amount not spent on acquiring new material).

The quantities of waste used for analysis are taken from the quantities of landfilled construction waste in Drisla in 2023 and projections for generated construction waste and debris in the Regional Waste Plans of the Ministry of Environment and Physical Planning. These quantities are given in Figure 2. The prediction parameters of the amount of generated waste are identical for all scenarios.

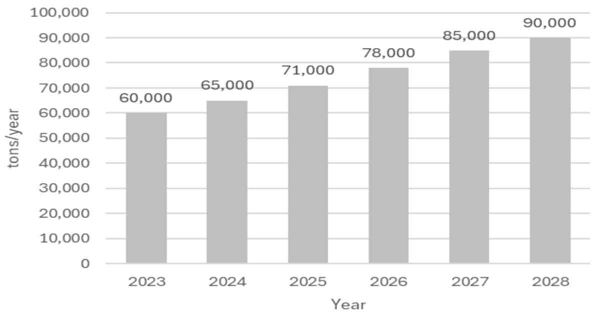

Fig. 2. Estimated CDW quantity delivered to Drisla from 2023 to 2028

In the analysis of investments, constant prices for waste disposal from the price list of the Public Enterprise Landfill Drisla in Skopje were used, with the possibility of correction in the next 6 years [10]. The prices for delivered CDW for landfilling are given in Figure 3. These prices are identical for all scenarios.

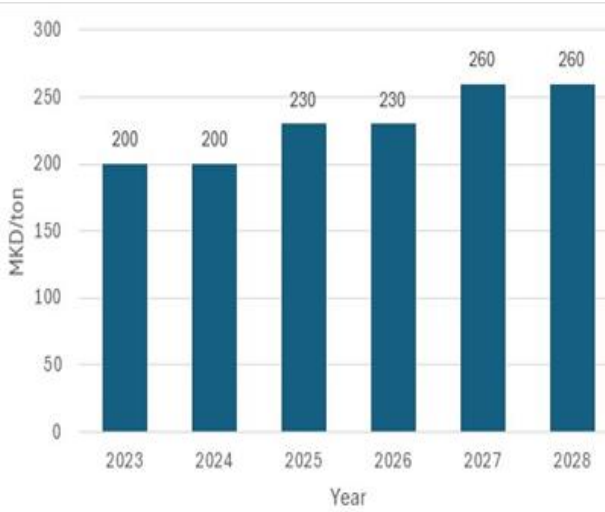

Fig. 3. Prices for undertaking CDW in Drisla from 2023 to 2028

Keeping this in mind, economy models are developed for all the scenarios: FT, ST and STM. To make the calculation easily comparable, few factors are taken into account:

Inflation is not calculated.

- All investment is calculated as delivered to the place of operation, commissioned, including training of personnel.
- All expenses (customs and other) are calculated in the price of investment.
- All profit/loss is calculated pre-taxed.

The total investments in equipment purchase and infrastructure preparation necessary for each scenario are given in Table 2.

T a b l e 2

Total investment for each scenario

	FT	ST	STM
Total investment in equipment and infrastructure (in euros)	154,365,000	67,035,000	56,580,000

3. RESULTS AND DISCUSSION

Selection of most feasible scenario is determined by the following criteria:

- Simplified ROI – return of investment,
- Execution time of the scenarios.

Calculations suggest that the FT scenario has a 12.2 year of ROI, which is logical having in mind the large investments for this scenario. ST scenario has a favourable ROI compared to FT, but the time of execution of this scenario is more than 2 years. This is due to the need for new urban and plan documentation, construction and mechanical projects and legal permits from the city and the municipalities. On the other hand, STM scenario has the best ROI, and the execution time is estimated at 6 months from the point of decision to implement the scenario. The operation of the equipment can be put in place after 6 months from the start of the purchasing from the city of Skopje, and in the same 6 months, a public campaign can be developed and executed so that the processes go simultaneously. The abovementioned data are summarized in Table 3.

T a b l e 3

ROI and execution time of each scenario

Assessment criteria	FT	ST	STM
ROI (years)	12.2	5.0	4.0
Execution time (years)	2.1	2.1	0.6

Measurable benefits from each of the proposed scenarios are reducing GHG emissions, lowering the landfilled CDW amount and increasing the recycled CDW amount. Using the emission factor for CDW recycling the CO_2 equivalent emission reduction due to execution of any scenario in the six-year calculation period is 18,031,840 kg CO_2-e [11]. The CDW left unproperly outside regulated landfill will be reduced by 449,000 tons. This amount of CDW would have been left in dumpsites in the DN Scenario. And the amount of CDW that will be recycled as secondary raw material and further used amounts to 179,000 tons. This contributes to lower emission of CO_2 due to lower mining processes, lower transport needed and lower natural resources consumption. The measurable environmental impacts are presented in Table 4.

Table 4

Environmental impact from implementation of any scenario

Additional parameters	All scenarios
GHG emission reduction (CO_2kg-e)	18,031,840
Reduction of CDW outside of landfill (t)	449,000
Amount of CDW recycled (t)	179,600

The immeasurable positive impacts are reflected through human health, soil, water, air quality, and socio-economic impact.

a) *Impact on human health*

In the long term, any of the proposed scenarios that would be implemented will positively influence the health of the citizens of the Skopje Region. It will contribute to establishing processes for the rational management of construction waste. The previous practice of leaving construction waste and debris in unregulated dumps and undefined locations is expected to significantly decrease. With a robust awareness campaign and enhanced efforts by inspection services, it is expected that a large portion of construction waste dumped in inappropriate locations will be affected by implementation of the activities. This will subject the waste to sorting, reuse of useful fractions, and recycling of fractions that can be used as buffer materials. This will directly reduce environmental pollution by around 50,000 tons of construction waste, decrease soil pollution, and subsequently reduce contamination of groundwater. Additionally, this will reduce the need for buffer materials from quarries, thereby decreasing air pollution from mining activities. Implementing the activities of these scenarios will lead to a reduction in the quantities of construction debris disposed of, elimination of small and micro-dumps everywhere, and an increase in public awareness regarding the quality of life and improvement of waste management practices.

b) *Socio-economic impact*

The implementation of the proposed scenarios will positively impact the socio-economic condition. It will introduce economic activity that contributes to better financing of public enterprises in the City of Skopje, especially the Drisla landfill. This enables the funds saved from the purchase of buffer materials to be invested in the development of the landfill, towards multiple systems to prevent waste creation, pollution prevention, and high-quality waste treatment for the waste from the Skopje planning region. The interest in establishing new processes in the circular economy in the Skopje planning region will increase and the economic conditions for employment will improve. Furthermore, establishment of improved waste management processes will be enabled, contributing to higher qualifications and better-paid job opportunities for those involved. The waste processing will reduce the amount of material being landfilled, extending the life of the Drisla landfill and reducing the need for new landfills.

c) *Impact on soil*

The implementation of these scenarios, designed for the treatment and management of construction debris and waste, will result in the rational use of land. Significant positive and long-term impacts on the soil are expected. Over 70 locations where construction waste was previously dumped will remain uncontaminated. Additionally, by establishing a waste flow for construction debris, the life of the Drisla landfill will be extended, reducing the need for new landfills. These solutions provide an opportunity for municipal authorities, through consistent compliance with legal obligations, to prevent any soil pollution from the disposal of construction debris and waste.

d) *Impact on air quality*

With the implementation of the proposed scenarios, long-term positive effects on air quality are expected. In areas where construction debris and waste are generated, practices for the selection, separation, and handling of construction waste are expected to improve. Furthermore, a reduction in open waste dumping and a decrease in dust content from waste are anticipated. At the location where the waste is processed, there is an expected generation of dust, which will be partially treated with water sprays. Emissions of harmful components from fuel combustion in the exhaust emissions are expected from the operation of machinery.

e) *Impact on the quality of surface and groundwater*

Since the construction activities planned for each scenario are not dependent on large quantities of water, environmental pollution due to emissions of waste waters is expected to be insignificant. Near the project site, where activities will be implemented, sprinklers are planned to be used to reduce dust from the crushing process of construction material, which could lead to emissions into groundwater through the soil and via the sewage system.

4. CONCLUSIONS

In this paper, four distinct scenarios have been outlined for the improved management and treatment of waste stemming from construction activities and construction debris within the Skopje Region. Each scenario presents a unique approach towards addressing the challenges associated with construction waste, spanning technical and organizational enhancements, economic viability, and environmental impact considerations. The scenarios delineated include Full Treatment, Selected Treatment, Selected Treatment on Mobile Equipment, and a baseline scenario of Do Nothing. Through a detailed description of each scenario's operational framework, including waste collection methods, treatment processes, and associated investments, this paper offers a comprehensive assessment of potential pathways for managing construction waste within the region. From a technical standpoint, the scenarios encompass a spectrum of waste treatment methodologies, ranging from comprehensive automated processes to more streamlined approaches. Economic analyses conducted for each scenario shed light on the financial implications of implementation, considering factors such as ROI and execution timelines of scenarios. Notably, the economic analysis reveals varying degrees of feasibility among the scenarios, with ST Mobile emerging as the most economically viable option, boasting a favorable ROI and relatively swift implementation timeframe. This scenario leverages mobile equipment for waste treatment, offering flexibility in deployment and minimizing operational delays.

Furthermore, the paper underscores the significant environmental benefits associated with the proposed scenarios, including decreased quantities of construction debris disposed of outside regulated landfills. This will result in reduced environmental damage and saved funds that were previously spent on clearing unregulated construction waste landfills. The recycling rates will increase, leading to reduced damage caused by mining activities for excavating landfill material. By adopting these measures, the region stands to mitigate environmental pollution, enhance soil and water quality, and improve overall air quality through more sustainable waste management practices. Other benefits include increased gains from the introduction of advanced technology and an improved level of qualifications for personnel in enterprises.

In addition to tangible environmental benefits, the implementation of these scenarios holds promising socio-economic implications for the Skopje Region. Beyond fostering economic activity and resource utilization efficiency, the proposed initiatives are poised to stimulate job creation, enhance public awareness, and bolster the region's transition towards a circular economy model.

In conclusion, the findings presented in this paper underscore the critical importance of proactive waste management strategies in mitigating the environmental impact of construction activities. By embracing innovative approaches and collaborative efforts, stakeholders in the Skopje Region can pave the way for sustainable development and pave a path towards a cleaner, more resilient future.

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