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Evaluating the Potential of Recycled Asphalt for Sustainable Road Construction: An Environmental and Economic Analysis

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Abstract

Objective: This study investigated the possibility of using recycled asphalt for road construction and maintenance in Kosovo. *Methods*: By analyzing statistical data from the Ministry of Infrastructure based on the status of infrastructure, the life cycle of asphalt, and investments in this area, this study determined the amount of asphalt that needs to be recycled. *Results*: The results showed that 1454008.5 m^3 of asphalt needs to be recycled in Kosovo. We studied using 10%, 15%, and 20% recycled asphalt in asphalt base courses. We determined the benefits of recycled asphalt in terms of environmental protection, energy savings, and low cost. Depending on the percentage of recycled asphalt, the savings in mineral mix ranged from 11% to 23% and the road bitumen dosage from 6 to 8.5%. *Novelty/Improvement*: The proposed method of reusing recycled materials can reduce the consumption of natural resources, energy, and financial costs and help protect the environment.

Keywords: Recycled Asphalt; Construction; Environmental; Kosovo; Road Network; Natural Resources.

1. Introduction

Asphalt is an artificial product made from various ingredients. It has been used in the construction sector for about 125 years, especially in railroad and road construction [1]. Advances in science and technology have enabled the recycling of asphalt, thus favoring its reuse in construction infrastructure. Recycling has resulted in extracting fewer raw materials from nature, saving energy, reducing costs, and protecting the environment [1]. The Republic of Kosovo covers an area of 10,905.25 km^2 [2]. The road network is 2434 km long and consists of 137.20 km (5.6%) of highways, 753.00 km (30.94%) of national roads, 1495.00 km (61.42%) of regional roads, and 18.8 km (2.00%) of connecting roads (MMPHI, 2023). All these roads are asphalted, and the thickness of the asphalt varies from 15 to 30 cm depending on the type of road [3]. According to the Ministry of Environment, Physical Planning, and Infrastructure (2023), the asphalt layer's thickness on Kosovo roads varies from 15 cm to 30 m, with an average road width of 7 m [3]. The impact of the asphalt business on the environment and economy can be reduced by using recycled asphalt pavement (RAP).

Recycled materials have been used for road construction for many years. RAP is used more frequently due to improvements in material processing machinery and mix technology. The benefits of using RAP include economic savings from reduced material consumption, environmental protection, and energy savings in the mix production [4]. Although asphalt mix is considered recyclable, indicating that RAP is a sustainable material, few studies have comprehensively investigated its effectiveness [5]. RAP is more economically and environmentally beneficial when a thin asphalt overlay is used than a new pavement. A net present value is assigned to the bitumen, the operation of the plant, the aggregates, and the transportation of the raw material [6]. In 1999, after two years of war and decades of

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communist administration, Kosovo was among the countries in Europe with the least developed and underfunded road infrastructure. Despite the recent increase in road infrastructure investment in the post-war period, Kosovo still lags behind neighboring and European countries. Indicators show that recent and ongoing investments in Kosovo's Road infrastructure have positive economic, environmental, and social impacts [2, 3]. Road repairs using asphalt recycling technology are more affordable and have a lower impact on the environment than traditional methods. RAP, the asphalt produced during road repairs, is recycled into recycled asphalt mix, which is then used to construct new roads [7]. The typical life of asphalt roads is 18 years. Many factors affect the actual results beyond the performance of concrete or asphalt [8]. Like other countries, there are financial constraints on road infrastructure investments in Kosovo [9]. Identifying appropriate financing options and techniques to raise the necessary funds for road infrastructure development is a major concern. Since traffic estimates indicate a significant increase in traffic, developing methods for financing road infrastructure will continue to be a problem for several years [10].

This study analyzes Kosovo's roads and road infrastructure investments from 2005 to 2022. It proposes different recycling solutions that are most appropriate in different circumstances. In addition, this study discusses the advantages and disadvantages of each solution. Taking the necessary steps to ensure that recycled asphalt is properly placed and maintained will ultimately save money and reduce waste in the long run. By taking appropriate steps to ensure that recycled asphalt is properly placed and maintained, Kosovo can make the most of its aging road infrastructure and save money. This paper presents a new analysis of the potential amount of recycled asphalt that can be easily determined without complex calculations based on the dimensions and thickness of the asphalt layers, their deterioration date, and when they need to be replaced. This simple method allows engineers to quickly analyze the amount of asphalt that can be recycled and use the design mix to recycle the new asphalt according to the laboratory methodology.

2. Research Methodology

This study investigated the use of recycled asphalt, evaluated the potential amount that could be used, and developed a calculation method to determine the feasible amount. It also examined the economic, environmental, and other benefits of using recycled asphalt in constructing roads and infrastructure where asphalt is the base material. This study collected statistical information on the condition and evolution of road infrastructure over time, analyzed asphalt service life, and determined the condition of roads and existing asphalt. Based on these findings, the potential amount of recycled asphalt that can be reused in layered structures and other road structures was calculated.

I. Study design: a quantitative research design was used, including a case study, data collection, data analysis, statistical analysis, and calculation and interpretation of data.

II. Data collection: the study was conducted using statistical data from the Ministry of Infrastructure on the condition of road infrastructure from 2006 to 2022. In addition, this study analyzed infrastructure investment before 2006 and road infrastructure investment from 2006 to 1975.

III. Data Analysis: The analysis was based on statistical data on road conditions and years of construction and involved various studies that examine asphalt service life. Years of construction were compared to the life of the asphalt and the time it takes to repair the asphalt layers and replace the last layer. In addition, the potential amount of recycled asphalt resulting from this data was calculated.

Two major routes (6 and 7) connecting the area with EU transit through Kosovo are part of a larger Southeast European core network (Figure 1) [3, 9].

Figure 1. Infrastructure of Kosovo

Most major and minor roads have been constructed or upgraded to highway standards, and work is ongoing on many others. Determining the amount of recyclable asphalt is critical because it can help determine the amount of recycled asphalt that can be used in Kosovo. Road repairs using recycled asphalt technology are more affordable and have a lower environmental impact than traditional methods. Asphalt roads typically last 18 years, but actual performance depends on many factors beyond the properties of concrete or asphalt [11]. Like many other countries, there are financial constraints on road infrastructure investments in Kosovo.

Table 1. Roads of Kosovo according to categories by years and category

Year	Motorway (Km)	National (Km)	Regional (Km)	Connecting roads (Km)	Total (Km)
2022	137.200	753.000	1495.000	48.800	2434.000
2021	137.150	753.440	1494.930	46.880	2432.400
2020	137.200	755.200	1486.300	46.880	2378.700
2019	137.200	665.200	1509.400	38.105	2311.700
2018	119.100	641.700	1313.900	..	2074.700
2017	108.000	630.400	1305.000	..	2043.400
2016	98.000	630.400	1305.000	..	2033.400
2015	78.000	630.400	1305.000	..	2013.400
2014	78.000	630.400	1294.700	..	2003.100
2013	78.000	630.400	1294.700	..	2003.100
2012	60.400	630.400	1294.700	..	1985.500
2011	38.000	630.400	1294.700	..	1963.100
2010	0.000	630.400	1294.700	..	1925.100
2009	0.000	630.400	1294.700	..	1925.100
2008	0.000	630.400	1294.700	..	1925.100
2007	0.000	630.400	1294.700	..	1925.100
2006	0.000	630.400	1294.700	..	1925.100
2005	0.000	630.400	1294.700	..	1925.100

In order to achieve this goal, a research methodology was used that included four main phases: Field studies, laboratory analysis, interpretation of results, and document evaluation (Figure 2).

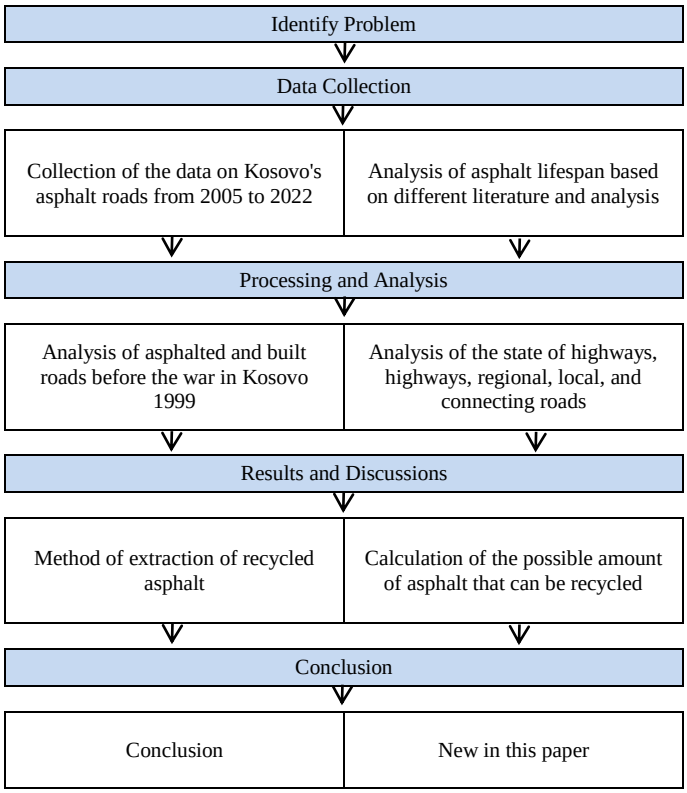

Figure 2. Flowchart of the methodology

3. Results and Discussion

3.1. History of Asphalt Recycling

The asphalt industry has had considerable success recycling asphalt pavement. Although asphalt pavement recycling was introduced in 1915, it did not catch on until the early 1970s, when asphalt binder prices increased due to the 1973 Arab oil embargo [12]. The asphalt industry responded to this situation by developing recycling technologies that helped reduce the need for asphalt binders and, thus, the cost of asphalt mixtures. Many of the processes originally developed during this period are still in use today and have become an integral part of routine pavement construction and rehabilitation operations [13]. Motivations for recycling include economic savings and environmental benefits. Recycling reduces the demand for non-renewable natural resources (both bitumen and aggregates), thus reducing the energy and emissions associated with the extraction and transportation of these raw materials [14].

In addition, recycling helps to avoid landfilling old pavement material that is removed during rehabilitation. Economic benefits come from the material cost savings that result from replacing some of the new aggregate and bitumen [15]. An asphalt mixture's bitumen and aggregate components account for most road construction costs. Advances in hot mix plant technology have enabled the successful integration of RAP and rejuvenators throughout the asphalt manufacturing process [16]. According to a 2017 survey, European countries, including Belgium, Finland, the United Kingdom, Hungary, and Slovakia, recycled over 90% of the available RAP to produce hot and warm asphalt for wearing courses [17].

3.2. Factors Affecting the Life of Asphalt

The longevity of asphalt depends on whether it is a completely new surface or just an overlay. The typical life of asphalt parking lots and roadways is 20 years. New surfaces can last up to 20 years and are often more durable. In contrast, the surface is more likely to deteriorate over time and is unlikely to last more than 10 to 15 years [18]. The exposure of asphalt to traffic, both in terms of quantity and type, affects its longevity. If asphalt pavement is used only for passenger car traffic, it should last much longer. However, its life is shortened when asphalt pavement supports heavy loads and large equipment [19]. If these problems are not corrected, it may be necessary to resurface the entire asphalt lot. Resurfacing the entire parking lot or street area is often more cost-effective when 25–35% of the area requires significant removal [5, 20]. Although asphalt roads are inexpensive, durable, and resilient, they have a regular life cycle. A properly constructed, low-traffic asphalt road installed by professionals can survive up to 25 years or more [21].

3.3. How to Calculate the Amount of Recycled Asphalt?

The longevity of asphalt depends on whether it is a completely new surface or just an overlay. The typical life of asphalt parking lots and roadways is 20 years. New surfaces can last up to 20 years and are often more durable. In contrast, the surface of an overlay deteriorates over time and is unlikely to last more than 10 to 15 years [18]. The exposure of asphalt to traffic, both in terms of quantity and type, affects its longevity. If asphalt pavement is used only for passenger car traffic, it should last much longer.

However, if asphalt pavement is used to support heavy loads and large equipment [19], its life would be shortened. If these problems are not corrected, it may be necessary to resurface the entire asphalt lot. Repaving the entire parking lot or road surface is often more cost-effective when 25%-35% of the surface area requires significant removal [20]. Although asphalt roads are inexpensive, durable, and resilient, they have a regular life cycle. A properly constructed asphalt road with low traffic installed by qualified professionals can survive up to 25 years or longer [21].

3.4. Pavement Demolition

Complete demolition of an existing sidewalk can provide recycled material. Mechanical tools, such as bulldozers or excavators, can accomplish this. Only small pieces of pavement can be used for this technique [22-25]. Large chunks of pavement produced by this retarded method may be more difficult to recycle due to their size [26]. Before being used as shoulder or subgrade material, the material must be crushed if it is contaminated with soil. In many locations in Kosovo, asphalt waste has been removed from existing roads in various forms, either by excavation (Figures 3 to 5) or by erosion (Figure 6).

Figure 3. Full-Depth Demolition

Figure 4. Full-Depth demolition of asphalt thickness 15 to 30 cm

Figure 5. Full-Depth Demolition of asphalt thickness 15 to 30 cm

Figure 6. Asphalt erosion on the roads that will be replaced with the final 5 cm layer

4. Calculation of the Possible Amount of Asphalt that Can be Recycled in Kosovo

In Kosovo, many roads have been asphalted for over 30 to 60 years, and about 80% need to be renewed. Many of these roads are restored with new asphalt, removing the old asphalt first, and about 80% of them need to be resurfaced. Many of these roads are being reconstructed with new asphalt, removing the old asphalt and then placing the new asphalt; these roads are being converted to two-lane roads [27]. The maximum service life of asphalt is 30 years [28]. However, in Kosovo, this service life is much shorter due to the poor quality of asphalt and companies' lack of experience working in road infrastructure [29]. Therefore, the average life of asphalt will not exceed 20 years. In addition, the rehabilitation and intervention of completed roads do not exceed 5 to 10 years after completion. Based on these data, the amount of asphalt that can be recycled can be calculated. Reconstruction of new roads in Kosovo usually takes place on average seven years after completion; removing the asphalt and paving a new layer is usually used. Erosion is usually up to 5 cm (Figure 6) since most roads have a final layer that is not basalt or abrasive materials, and the new layer should be made of abrasion-resistant materials.

As shown in Table 2, roads in Kosovo are considerably old, with about 1925.1 km (or about 13475700.00 m^2 calculated using average road width) built more than 30 years ago. The average thickness of asphalt is about 15 cm, as shown in photo 4. There are about 202135.00 m^3 of asphalt on roads older than 30 years, which is the maximum life of asphalt. No investments were made in road infrastructure before 2010.

Table 2. Roads of Kosovo according to categories: Calculation of the possible amount of asphalt that can be recycled

Year	Motorway	Construction progress	National	Construction progress	Regional	Construction progress	Connecting roads km	Construction progress	Total	7 m road width is taken as an average	15 cm thickness of the asphalt
	km	km	km	km	km	km	km	km	km	m^2	m^3
2022	137.2	-	755.0	-	1495.0	-	48.8	1.92	2434.00	17038000.00	2555700.00
2021	137.15	-	755.0	-	1494.93	8.6	46.88	-	2432.40	17026800.00	2554020.00
2020	137.2	-	755.0	89.8	1486.3	-	46.88	8.77	2378.70	16650900.00	2497635.00
2019	137.2	18.1	665.2	23.5	1486.3	172.4	38.105	38.10	2311.70	16181900.00	2427285.00
2018	119.1	11.1	641.7	11.3	1313.9	8.9	-	-	2074.70	14522900.00	2178435.00
2017	108	10	630.4	-	1305	-	-	-	2043.40	14303800.00	2145570.00
2016	98	20	630.4	-	1305	-	-	-	2033.40	14233800.00	2135070.00
2015	78	-	630.4	-	1305	10.3	-	-	2013.40	14093800.00	2114070.00
2014	78	-	630.4	-	1294.7	-	-	-	2003.10	14021700.00	2103255.00
2013	78	17.6	630.4	-	1294.7	-	-	-	2003.10	14021700.00	2103255.00
2012	60.4	22.4	630.4	-	1294.7	-	-	-	1985.50	13898500.00	2084775.00
2011	38	38	630.4	-	1294.7	-	-	-	1963.10	13741700.00	2061255.00
2010	0	-	630.4	-	1294.7	-	-	-	1925.10	13475700.00	2021355.00
2009	0	-	630.4	-	1294.7	-	-	-	1925.10	13475700.00	2021355.00
2008	0	-	630.4	-	1294.7	-	-	-	1925.10	13475700.00	2021355.00
2007	0	-	630.4	-	1294.7	-	-	-	1925.10	13475700.00	2021355.00
2006	0	-	630.4	-	1294.7	-	-	-	1925.10	13475700.00	2021355.00
2005	0	-	630.4	630.4	1294.7	1294.7	-	-	1925.1	13475700	2021355.00
Total		137.2	km	755	km	1494.9	km	48.8	km		

1975 to 2010:

- Considering that only about 70% of this surface is completely removed and the rest is corroded and resurfaced, we can expect this amount of recycled asphalt.
- With an average thickness of the asphalt of about 15 cm (Figures 3 to 5), we can obtain 1414948.5 m^3 of recovered asphalt.

2011 to 2018:

- This amount would be increased to 781200.00 m^2 × 0.05 = 39060.0 m^3, with the remainder being repaired by erosion with a depth of 5 cm (Figure 6).
- After calculating the total amount of asphalt that could be recycled, we arrive at the following figure: 1454008.5 m^3 = 1414948.5 + 39060 m^3. This is the highest amount of asphalt that can be recycled.

The importance of recycling asphalt from the point of view of environmental protection, energy consumption, and economic efficiency was studied by analyzing the use of recycled asphalt in a proportion of 10%, 15%, and 20% for the asphalt base layer [30]. The following components were used to produce asphalt mixtures.

- Stone powder;
- Smaller stone fractions 0/4, 4/8, 8/16, and 16/31;
- Bitumen for road construction 50/70.

Three recycled asphalt mixtures with different proportions of road bitumen (5.2%, 5.50%, and 6.10%) were studied in the laboratory to prepare test formulations [1, 31]. Based on the laboratory results, an ideal granulometric composition of 4.90% 50/70 road bitumen was established following the standard EN 12697-8 and considering the percentage of voids and their filling. The General Technical Conditions for Road Construction specify limit values [32]. Formulations for the production of asphalt mixtures were prepared. Following laboratory tests, the production of BNHS-22 was started, an asphalt mixture with different proportions of recycled asphalt (10%, 15%, and 20%) [33]. The obtained results are presented in Table 3 and show the possible savings in producing asphalt mixtures. Depending on the percentage of recycled asphalt, the savings in the mineral mix ranged from 11% to 23% and in the dosage of road bitumen from 6% to 8.5%.

Table 3. In the manufacturing of mixed asphalt, savings were planned for and accomplished

Bituminized bearing wear layer BNHS-22	10% recycled asphalt	15% recycled asphalt	20% recycled asphalt
Realized savings of mineral mixture	about 11%	about 19 %	about 23 %
The expected proportion of road bitumen before production based on laboratory tests	4.90 – 5.10 %	4.80 – 5.00 %	4.80 – 5.00 %
Planned savings in the dosing of road bitumen	5.20-6.00 kg/t (10.50 – 12.20 %)	7.80-9.10 kg/t (15.80 – 18.50 %)	10.40-12.10 kg/t (21.20 – 24.70 %)
Real saving of road construction bitumen	4 kg/t (8.33 %)	4.20 kg/t (8.57 %)	3.00 kg/t (6.12 %)

The granulometric composition of the mixture, the density of asphalt samples according to EN 12697-5, the density of asphalt mixtures according to EN 12697-6, the percentage of voids, and the filling of voids according to EN 12697-6 were determined by laboratory tests. One of the most common uses of construction waste worldwide is the admixture of recycled asphalt aggregates in new asphalt mixtures [34]. Recycled asphalt aggregates have been proven in road construction in established European countries over many years, first on test sections under real conditions and then as a standard material. Recycled asphalt has long been used to produce fresh asphalt in European countries [35].

5. Conclusion

The Republic of Kosovo, with an area of 10905.25 km^2, has a road network of 2434 km, consisting of 137.20 km (5.6%) of highways, 753.00 km (30.94%) of national roads, 1495.00 km (61.42%) of regional roads, and 18.8 km (2.00%) of connecting roads. Many roads in Kosovo are rehabilitated and built with new asphalt, where the old asphalt is first removed and then replaced with new asphalt, or old roads are converted into two-lane roads. The maximum service life of asphalt is 30 years. However, in Kosovo, this lifespan is much shorter due to the poor quality of asphalt and the lack of experience of companies involved in infrastructure work. Moreover, rehabilitation works and interventions on completed roads are carried out 5 to 10 years after completion using different proportions of reclaimed asphalt. Recycled asphalt has long been used in European countries to produce fresh asphalt. However, asphalt recycling has been used only in Kosovo in the last two decades. This work determined the amount of asphalt that needs to be recycled in Kosovo. It is estimated at 1454008.5 m^3. The analysis of 10%, 15%, and 20% recycled asphalt in asphalt

base courses showed the importance of recycling asphalt in terms of environmental protection, energy savings, and economic prospects. Depending on the percentage of recycled asphalt, the savings in mineral mix ranged from 11% to 23% and the road bitumen dosage from 6% to 8.5%. Asphalt recycling in Kosovo is crucial for conserving natural resources and the environment. It reduces the demand for new natural resources, energy, and transportation and promotes integrated natural resource management. Kosovo should adopt recycling solutions such as in-place and in-plant technologies that reduce resource waste and lower road maintenance and construction costs to maximize the cost-saving benefits of recycled asphalt. The decision to use hot or cold methods should be based on cost, environmental impact, and the ability to produce a mix that meets design specifications.

6. Declarations

6.1. Author Contributions

Conceptualization, Mu.A. and Mi.A.; methodology, V.K.; formal analysis, Mu.A.; investigation, Mu.A; data curation, Mu.A; writing—original draft preparation, Mu.A. and V.K.; writing—review and editing, Mu.A.; visualization, V.K.; supervision, Mi.A.; funding acquisition, V.K. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available in the article.

6.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

6.4. Conflicts of Interest

The authors declare no conflict of interest.

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