EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology 2023, 24(2), 79–86
https://doi.org/10.12912/27197050/156965
ISSN 2719-7050, License CC-BY 4.0

Received: 2022.10.24
Accepted: 2022.12.10
Published: 2023.01.01

Life Cycle Assessment of Asphalt Mix Containing Jordanian Oil Shale Ash

Rozalya Alhunity[1], Salah H. Aljbour[2*], Emad N. El Qada[2]

[1] The Engineering Management Master Program, Faculty of Engineering, Mutah University, Karak, Jordan
[2] Chemical Engineering Department, Faculty of Engineering, Mutah University, 61710 Al-Karak, Jordan
* Corresponding author's e-mail: saljbour@mutah.edu.jo

ABSTRACT
The focal theme of this study is to evaluate the life cycle of asphalt mix containing Jordanian oil shale ash (OSA). Life cycle assessment (LCA) approach was conducted to assess the environmental impact of all manufacturing stages of the asphalt mix from Global warming potential (GWP) and energy consumption (EC) perspectives. The documentation for the LCA study was done in accordance with ISO 14044:2006 standards for the research's goal and scope, inventory analysis, impact assessment, and interpretation. The results revealed that replacing the asphalt mix partially with Jordanian OSA (10 wt.%) resulted in slight reduction in both GWP and EC. A reduction of 2.83% and 4.8% for GWP and EC, respectively, was obtained.

Keywords: oil shale ash, asphalt mix, inventory analysis, life cycle assessment, global warming, industrial waste.

INTRODUCTION

Jordan is regarded as a poor country in terms of crude oil and natural gas resources, but it is abundant in shale oil resources. The oil shale resources in Jordan underpin more than 60% of the Jordanian geography, amounting to 40–70 billion tons. Oil shale (OS) in Jordan may be found in a few outcrops and largely in the subsurface (Yihdego et al., 2018). The Jordanian government's energy policy intends to boost the contribution of oil shale sources to 10% by 2025, while lowering imported energy resources, such as crude oil and natural gas. There are two methods for benefiting oil shale for energy generation. It has been proposed that oil shale might be utilized to generate the energy required to run power plants by direct combustion. Shale oil may also be extracted or retorted from oil shale and refined into various fuel fractions (Aljbour, 2019). Many corporations have shown an interest in investing in building power plants that use direct OS burning technology. Jordan's first electric power plant, Attarat, has a 470 MW output capacity based on direct OS combustion. The Jordanian government has already signed eight memorandums of understanding with a number of foreign and domestic firms to further investigate oil shale projects (Komendantova et al., 2022).

Massive quantities of oil shale ash are expected to be produced each year as a consequence of oil shale burning. In fact, Jordanian oil shale contains around 50% ash. The ash percentage in certain deposits, such as Sultani oil shale, reached 70% (Aljbour, 2016). Ash generation as a result of oil shale exploitation poses a number of challenges, including ash treatment and usage. As the amount of ash generated increases, ash-storage facilities will be challenged, as well as the expense of management, transportation, and disposal. Direct dumping on land may have an effect on the structure and qualities of the soil. Using ash in engineering applications might be a potential environmental solution to the material's disposal dilemma. However, ash disposal must be handled properly to eliminate or minimize any detrimental environmental consequences. Oil shale ash (OSA) has been studied for a wide range of engineering applications. OSA has been shown to be useful in the production of Portland cement (Al-Otoom, 2005), cement-treated base (Hadi et al., 2008), asphalt mix (Khedaywi and Al-Qadi, 2008), self-compacting concrete (Ashteyat et al., 2012), and ceramics (Gorokhovskii et al., 2002; Luan et al., 2010; Hamadi and Nabih, 2012; Aljbour, 2016). Furthermore, OSA has been used as an asphalt modifier (Ghuzlan et al., 2013), a concrete binder (Al-Hasan, 2006; Al-Hamaiedh et al., 2010), and as a pyrolysis catalyst (Aljeradat et al., 2021). Another aspect of using OSA is to stabilize problematic soils (Hadi et al., 2008).

Al-Masaeid et al. (1989) quantitatively assessed the utilization of Jordanian oil shale ash as a partial substitute for asphalt binder in bituminous paving mixes under normal and freezing and thawing conditions. Under normal and freeze thaw conditions, asphalt mixtures with varying levels of ash were subjected to Marshall and indirect tensile tests. The results of the tests showed that substituting ash up to 10% by volume of asphalt improved the performance of the mixes under both conditions. Asi and Assa'ad (2005) investigated the effect of Jordanian oil shale fly ash on asphalt mixes. Fly ash may replace up to 50% of the mineral filler without affecting the performance properties of asphalt concrete mixes. When the strength properties of the tested asphalt concrete mixes were compared, it was determined that substituting 10% of the mineral filler with fly ash was the best replacement percentage. Azzam and Al-Ghazawi (2015) examined the effects of using OSA in instead of hot mix asphalt's conventional limestone filler. The hot mix asphalt using OSA filler produced superior performance than that with the control limestone filler, according to measurements of resilient modulus, creep, and fatigue. Additionally, varied oil shale filler aggregate percentages to the entire limestone control samples were made as part of their investigation on the incorporation of oil shale filler aggregate into hot mix asphalt pavement. Their findings showed that in addition to the hot mix asphalt pavement's necessary qualities being met, Marshall stability had increased by 10% to 20% in comparison to the all-limestone formulations. Long-term, the OSA has a favorable impact on increased fatigue resistance (Azzam et al., 2016).

All Investigations regarding the use of Jordanian OSA in asphalt mix production focused on the mechanical properties of the mix. No studies considered the environmental and socio-economic impacts. In this study, life cycle assessment of asphalt mix containing Jordanian oil shale ash is carried out. The life cycle assessment (LCA) method is used to assess the environmental impacts of producing a product from raw material extraction to final disposal. It is a scientific quantitative evaluation technique that takes into account the entire life cycle (from cradle to grave). LCA can be used as a technical tool to assess the environmental impact of a product, manufacturing process, packaging, or any activity over the course of a product's or service's entire life cycle (Singh et al., 2017).

ENVIRONMENTAL ASSESSMENT

The LCA for the environmental impact of OSA-based asphalt mix was performed in this paper using the ISO 14040 guidelines. It is divided into four stages: goal and scope definition, inventory analysis, impact assessment, and interpretation (ISO-14040, 2006).

Goal and scope

The primary goal of this research is to assess and compare the environmental impact of partially replacing the mineral fillers in asphalt mixes with OSA to that of a standard asphalt mix. The cradle to gate approach was used for the LCA, which included raw materials extraction, raw material transportation, and asphalt mix manufacturing. The functional unit for asphalt mix produced is defined as the total amount of materials required to produce 1 ton of asphalt mix. Two distinct models have been developed, the first for standard asphalt mix, designated as (Normal), and the second for asphalt mix replacement, designated as (AM10) where 10% of aggregate (by wt.) was replaced by OSA. Figure 1 shows the stages and system boundaries considered in the LCA.

Inventory analysis

Material flows and energy consumption are obtained from the corresponding authorities of each site involving a process in the LCA. Energy consumption is determined based on the amount of fuel and/or electricity consumed during the extraction, transportation and processing of the materials.

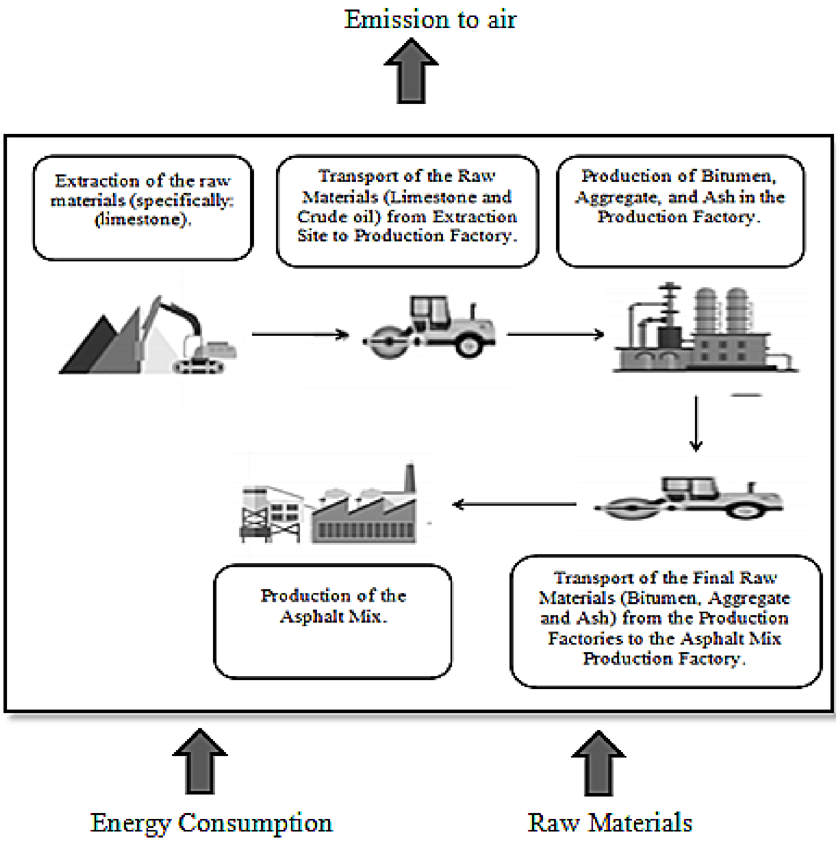

Figure 1. Stages and system boundaries considered in the LCA

Stage I – Extraction of the raw materials

In this stage, the extraction of limestone is only considered. Crude oil extraction is not considered as the crude oil is imported and not extracted locally. The extraction of OS is not considered in the LCA as its extraction is not scoped for asphalt mix production. Energy consumed during limestone extraction is mainly fuel consumed by the trucks. The extraction of limestone was done in Al-Aghwar / Sweimah area. Table 1 shows the quantity of fuel consumed in this stage.

Stage II – Transportation of the raw materials

After the extraction stage, raw materials are transported to a processing factory to produce the final raw materials for asphalt mix production. The limestone is transported to a processing factory to produce aggregate. The crude oil is transported to a petroleum refinery to produce bitumen. Crude Oil is transported from the Iraqi border (Al-Karamah border crossing) to Jordan Petroleum Refinery Company (JPRC). Energy consumption in this stage is due to fuel consumption only. Material flows and fuel consumption involved in this stage are given in Table 2.

Stage III – Production of the final raw materials

In this stage, the production of the final raw materials namely: limestone and bitumen are considered. The energy consumption and material flows of the final raw materials are shown in Table 3. Bitumen is produced from crude oil via a sequence of unit operations. These unit operations utilize both fuel and electricity during the production of bitumen. For limestone production, equipment and machines required to produce the limestone are operated on electricity.

Table 1. Quantity of fuel consumed in the first stage

Raw materials	Trucks	Fuel consumption (L/day/truck)	No. of trucks	Fuel consumption (L/ton)
Limestone (300 m^3/day)	Crusher truck	180	10	4.3
	Shovel truck	200	10	4.8

Table 2. Material flows and fuel consumption involved in stage II

Materials	Distance	Fuel consumption (L/day/truck)	No. of trucks	Fuel consumption (L/ton)
Crude Oil (1284223 ton/year)	330 km (AL-Karamah border - JPRC)	270	165	9.0
Limestone (300 m^3/day)	600	80	15	2.9

Table 3. Energy consumption and material flows involved in the production of the final raw materials (2019)

Final raw materials	Fuel consumption	Electricity consumption
Bitumen (208000 ton/year)	183.2 MJ/ton	47.2 MJ/ton
Aggregate (300 m^3/day)	0	4.0 MJ/ton

Stage IV – Transportation of the final raw materials

In this stage, the final raw materials needed to produce the asphalt mix are transported to the asphalt mix production factory, which is located in Wadi AL-Qattar / east of Uhud area. The amount of final raw materials and the amount of fuel consumed during the transportation of the final raw materials are shown in Table 4. All the data for this stage are obtained from the drivers who are in charge of transporting the bitumen from JPRC, the aggregate from Al-Aghwar, and OSA from the El-Lajjun area to Wadi AL-Qattar area.

Stage V – Production of the asphalt mix

At this stage, the final raw materials are mixed to produce the asphalt mix. The amount of energy consumed and the plant capacity are shown in Table 5.

Impact assessment

Individual inventory analysis results are linked to specific environmental impact categories during the environmental impact assessment phase, and their influence for each category is expressed with an impact category indicator (Laiblová et al., 2019). The life cycle assessment carried out in this study used two midpoint impact indicators, namely: global warming potential (GWP) and energy consumption (EC). Emission levels are converted into CO_2 equivalents to allow the global warming impact of different greenhouse gases to be combined. This conversion is based on the amount of warming that each gas contributes to the greenhouse effect. One kilogram of CO_2 equivalents is equivalent to one kilogram of CO_2 emissions. One kilogram of nitrous oxide (N_2O) equals 298 kilograms of CO_2 equivalents, while one kilogram of methane (CH_4) equals 25 kilograms of CO_2 equivalents. Accordingly, the GWP is estimated as follows (EPA, 2020):

$$\mathrm{GWP}\left(\mathrm{kg}\frac{\mathrm{CO_{2eq}}}{\mathrm{ton}}\right) = \mathrm{ER_{CO_2}} + 25\mathrm{ER_{CH_4}} + 298\mathrm{ER_{N_2O}} \tag{1}$$

where: ER_{CO_2}, ER_{CH_4} and ER_{N_2O} are the emission rate of CO_2, CH_4 and N_2O respectively.

The emission rates are estimated based on the emission factors for greenhouse gas inventories. Table 6 shows the emission factors for greenhouse gases for mobile combustion for on-road and off-road trucks, and electricity use.

Interpretation

Life cycle interpretation (LCI) is a method for identifying, quantifying, verifying, and evaluating information derived from inventory analysis

Table 4. Material flows and Fuel consumption during the transportation of the final raw materials

Materials	Amount (ton/year)	Distance	Fuel consumption (L/day/truck)	No. of trucks	Fuel consumption (L/ton)
Bitumen	14598	25 km (JPRC - Wadi AL-Qattar)	270	2	9.6
Aggregate	260571.6	90 km (Al-Aghwar - Wadi AL-Qattar)	80	50	3.6
OSA	28952.4	150 km (El-Lajjun - Wadi AL-Qattar)	80	5	3.6

Table 5. Plant capacity and energy consumption for the asphalt mix production plant

Plant capacity	304122 ton/year
Electricity consumption	35 MWh/year
Fuel consumption	8.2 L/ton

results. During the interpretation phase, the results of the inventory analysis and impact assessment are summarized. The interpretation should structure the LCI phase results to assist in determining the significant issues, in accordance with the goal and scope definitions, and in collaboration with the evaluation element (Hernandez et al., 2019). The interpretation results are presented in the next section.

RESULTS AND DISCUSSION

The energy consumption is estimated for each stage for the two scenarios (Normal and AM10). Figure 2 shows the total amount of energy consumed during each stage for the two scenarios. Results indicate that the energy consumption is reduced in stages I, II and III when incorporating the OSA in the asphalt mix. The reduction in energy consumption are 10, 9.7, and 2.6% for stages I, II and III respectively. The energy consumption for both Normal and AM10 scenarios were the same in stages IV and V. The total energy consumption involved in all stages are 862.3 and 821.1 MJ/ton for Normal and AM10 scenarios respectively. This indicates 4.8% reduction in energy consumption when incorporating the OSA in the asphalt mix. Figures 3-5 show the CO_2, CH_4 and N_2O emission rate respectively for each stage. Figure 3 indicate that the CO_2 emissions are reduced in stages I and III when incorporating the OSA in the asphalt mix. The reduction in CO_2 emissions are 10.0 and 3.78% for stages I and III respectively. In stage IV, the CO_2 emission increased by 6.2% due to the extra mileage traveled in transporting the OSA to the asphalt mix production plant. The CO_2 emissions for both Normal and AM10 scenarios were the same in stages II and V.

Figure 4 indicate that the CH_4 emissions are reduced in stages I, II and III when incorporating the OSA in the asphalt mix. The reduction in CH_4 emissions are 10.1, 1.8, and 5.4% for stages I, II and III respectively. In stage IV, the CH_4 emission increased by 21.7%. The CH_4 emissions for both Normal and AM10 scenarios were the same in stage V. Figure 5 indicate that the N_2O emissions are reduced in stages I, II and III when

Table 6. Emission Factors ((EPA, 2020))

Category	Emission factor		
	CH_4	CO_2	N_2O
Electricity use	0.085 (lb/ MWh)	947.2 (lb/ MWh)	0.012 (lb/ MWh)
Fuel combustion during operations	0.23 (g/gallon)	10.21 (kg/gallon)	0.47 (g/gallon)
Fuel consumption during on-road transportation	0.002 (g/ton-mile)	0.207 (kg/ton-mile)	0.0046 (g/ton-mile)

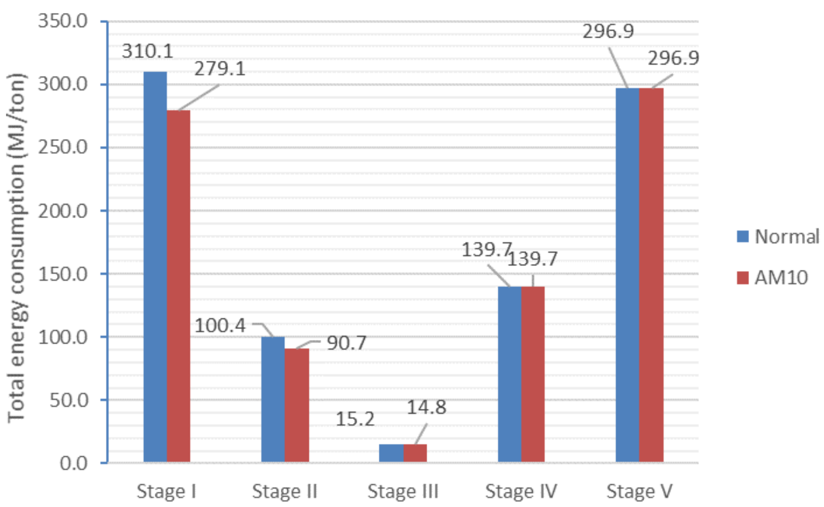

Figure 2. Total energy consumption for all stages involved in asphalt mix production Phases

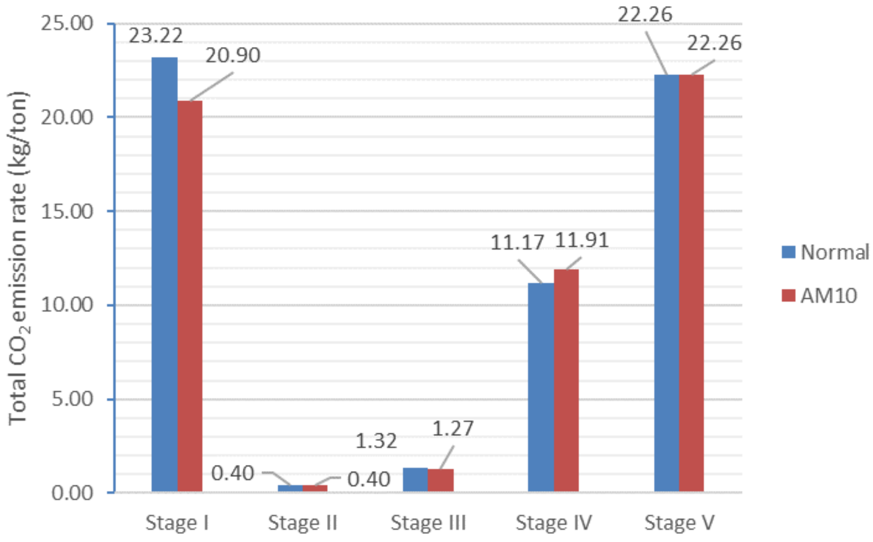

Figure 3. Total CO_2 emission rate for all stages involved in asphalt mix production phases

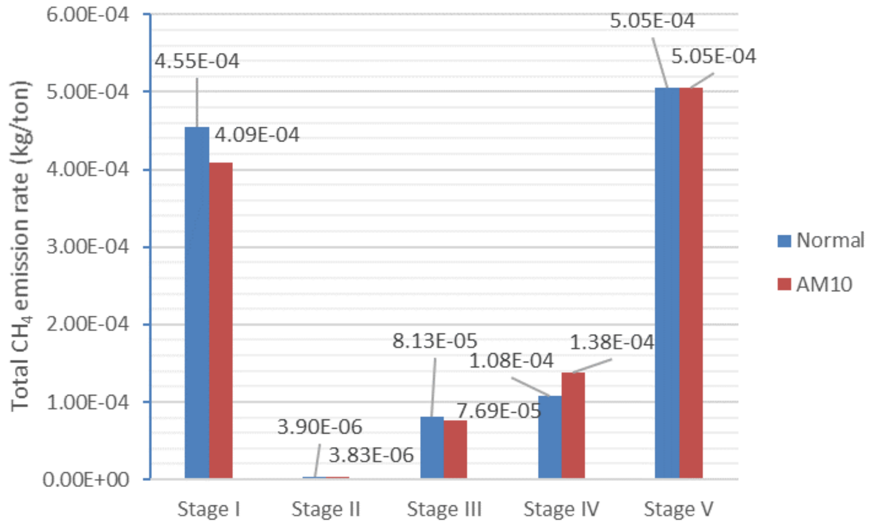

Figure 4. Total CH_4 emission rate for all stages involved in asphalt mix production phases

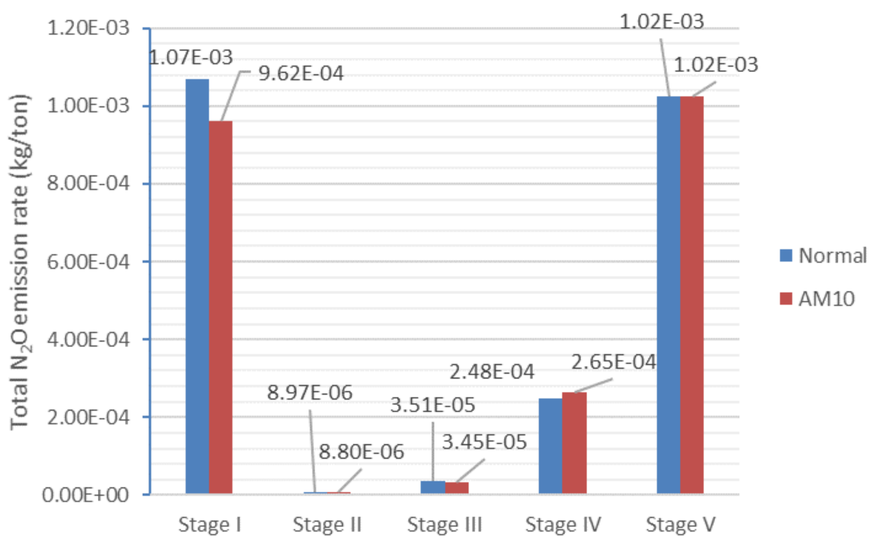

Figure 5. Total N_2O emission rate for all stages involved in asphalt mix production phases

incorporating the OSA in the asphalt mix. The reduction in N_2O emissions are 10.1, 1.9, and 1.7% for stages I, II and III respectively. In stage IV, the N_2O emission increased by 6.4%. The N_2O emissions for both Normal and AM10 scenarios were the same in stage V. The GWP for both Normal and AM10 scenarios are 59.11 and 57.44 kg CO_2 equivalent/ton respectively. This indicates 2.83% reduction in GWP when incorporating the OSA in the asphalt mix. The GWP reported in this study is in agreement with literature values. Mukherjee (2016) conducted LCA for asphalt mixtures containing varying quantities of recycled materials as a substitute for virgin materials as well as chemical additives. Recycled asphalt shingles (RAS) and reclaimed asphalt pavement (RAP) were taken into consideration as alternatives to aggregate and binder in the study. A mix with no RAP or RAS and 5% virgin liquid asphalt binder (Mix 1) and another mix with 15% RAP, 3% RAS, and 4.2% virgin liquid asphalt binder (Mix 2) were compared with respect to GWPs. The LCA accounted for the supply of raw materials, transportation, and manufacturing-processes that fall within the bounds of phases. The results indicated 58.6 and 35.9 kg CO_2 equivalent/ton for Mix 1 and Mix 2 respectively.

Based upon the current study's findings, AM10 Scenario is more sustainable than Normal scenario in terms of EC and greenhouse gas emissions as lower levels of energy consumption and greenhouse gas emissions have been achieved. Despite the fact that a slight reduction in GWP and EC was achieved, the partial replacement of asphalt mix with OSA could help in minimizing the consumption of natural resources of limestone required for the production of asphalt mix. Moreover, using OSA in the asphalt mix assists to get rid of large amounts of solid waste (OSA) resulting from the combustion of oil shale, solve the ash disposal dilemma and thus preserve the environment. From economical point of view, this will reduce the cost of mining, transportation and the production of aggregate that is used in the asphalt mix. This would also contribute to reducing high OSA disposal costs and thus improve the economics of oil shale exploitation. Nowadays, the reuse (utilization) of waste is of utmost important as a mean to protect the environment especially with increasingly stringent environmental regulations. Finally, it is advisable to construct the asphalt mix production plant as close as feasible to the OSA site to reduce the transportation distance and hence the greenhouse gas emissions.

CONCLUSIONS

This study presents the LCA of asphalt mix to evaluate the environmental impact of asphalt mix produced by partial replacement of natural aggregates (limestone) with Jordanian OSA. Asphalt mix containing 10 wt.% of OSA (AM10) was compared with standard asphalt mix (Normal) and both scenarios were assessed in terms of GWP and EC. Replacing the asphalt mix partially with Jordanian OSA has resulted in a slight decrease in the greenhouse gas emissions in stages I, II and III whereas stage IV has witnessed a slight increase in the greenhouse emissions which can be attributed to the long distance traveled in transporting the OSA.

In light of the results obtained, greenhouse gas emissions of AM10 Scenario were 2.83% lower than greenhouse gas emissions of Normal Scenario. This would lead to decrease the environmental impact of asphalt mix slightly. An overall decrease of 4.8% in EC was achieved by using OSA scenario (AM10). Findings of this study indicate that the utilization of Jordanian OSA in the asphalt mix can primarily solve the problem of OSA accumulation caused by the combustion of oil shale, which is considered a hazardous waste to the environment and in the second degree it contributes slightly in the reduction of GWP and EC. That is, replacing the asphalt mix with Jordanian OSA would help in managing the accumulation of an undesirable waste and environmentally hazardous material (OSA), appropriately and protect the environment from any potential/unexpected danger. It helps also to open new horizons and developing new potential utilizations of OSA as a resource.

REFERENCES

1. Al-Hamaiedh H., Maaitah O., Mahadin S. 2010. Using oil shale ash in concrete binder, Electronic Journal of Geotechnical Engineering, 15, 601–608.
2. Al-Hasan M. 2006. Behavior of concrete made using oil shale ash and cement mixtures, Oil shale, 23, 135–143.
3. Al-Masaeid H., Khedaywi T., Smadi M. 1989. Properties of asphalt-oil shale ash bituminous mixtures under normal and freeze-thaw conditions, Journal of

the Transportation Research Board, Transportation Research Record, 54–62.

4. Al-Otoom A.Y. 2005. A thermodynamic study on the utilization of Jordanian oil shale in the cement industry, Oil shale, 22, 37–49.
5. Aljbour S.H. 2016. Production of Ceramics from Waste Glass and Jordanian Oil Shale Ash, Oil shale, 33, 260–271.
6. Aljbour S.H. 2019. Intensification of Shale Oil Extraction from Oil Shale – An Alternative Solution for Sustainable Energy in Jordan, Journal of Engineering Science and Technology, 14, 1764–1675.
7. Aljeradat R.A., Aljbour S.H., Jarrah N.A. 2021. Natural minerals as potential catalysts for the pyrolysis of date kernels: effect of catalysts on products yield and bio-oil quality, Energy Sources, Part A: Recovery, Utilization, Environmental Effects, 1–9.
8. Ashteyat A.M., Haddad R.H., Yamin M.M. 2012. Production of self-compacting concrete using Jordanian oil shale ash, Jordan Journal of Civil Engineering, 6, 202–214.
9. Asi I., Assa'ad A. 2005. Effect of Jordanian oil shale fly ash on asphalt mixes, Journal of Materials in Civil Engineering, 17, 553–559.
10. Azzam M.O., Al-Ghazawi Z. 2015. Evaluation of incorporating oil shale filler aggregate into hot mix asphalt using Superpave mix design, Construction and Building Materials, 101, 359–379.
11. Azzam M.O., Al-Ghazawi Z., Al-Otoom A. 2016. Incorporation of Jordanian oil shale in hot mix asphalt, Journal of Cleaner Production, 112, 2259–2277.
12. EPA. 2020. GHG Emission Factors Hub. Envronmental Protection Agenccy, USA.
13. Ghuzlan K., Al-Khateeb G., and Abu Damrah A. 2013. Using oil shale ash waste as a modifier for asphalt binders, Journal of Material Cycles and Waste Management, 15, 522–529.
14. Gorokhovskii A., Gorokhovskii V., Mescheryakov D., Kopchekchi A. 2002. Glass ceramics based on oil shale ash, Glass Ceramics, 59, 191–193.
15. Hadi N.A.R.A., Khoury H.N., Suliman M.R. 2008. Utilization of bituminous limestone ash from EL-LAJJUN area for engineering applications, Acta Geotechnica, 3, 139–151.
16. Hamadi A., Nabih K. 2012. Alkali activation of oil shale ash based ceramics, E-Journal of Chemistry, 9, 1373–1388.
17. Hernandez P., Oregi X., Longo S., Cellura M. 2019. Life-cycle assessment of buildings. Handbook of Energy Efficiency in Buildings (Elsevier).
18. ISO-14040. 2006. Environmental management-Life cycle assessment-Principals and framework. International Standard ISO 14040. In.: International Organization for Standardization-ISO Geneva, Switzerland 2006.
19. Khedaywi T., Al-Qadi A. 2008. Effect of oil shale on fatigue performance of asphalt paving mixtures, Proceedings of ICCBT, 301–314.
20. Komendantova N., Marashdeh L., Al-Salaymeh A., Al Twassi S., AlBeek R., Hassouneh K. 2022. On the crossroad–renewable energy sources or shale oil? Understanding patterns of social attitudes in Jordan, OPEC Energy Review, 46, 3–30.
21. Laiblová L., Pešta J., Kumar A., Hájek P., Fiala C., Vlach T., Kočí V. 2019. Environmental impact of textile reinforced concrete facades compared to conventional solutions – LCA case study, Materials, 12, 3194.
22. Luan J., Li A., Su T., Cui X. 2010. Synthesis of nucleated glass-ceramics using oil shale fly ash, Journal of Hazardous Materials, 173, 427–432.
23. Mukherjee A. 2016. Life cycle assessment of asphalt mixtures in support of an environmental product declaration. National Asphalt Pavement Institute, Lanham, MD, USA.
24. Singh M., Choudhary K., Srivastava A., Sangwan K.S., Bhunia D. 2017. A study on environmental and economic impacts of using waste marble powder in concrete, Journal of Building Engineering, 13, 87–95.
25. Yihdego Y., Salem H.S., Kafui B.G., Veljkovic Z. 2018. Economic geology value of oil shale deposits: Ethiopia (Tigray) and Jordan, Energy Sources, Part A: Recovery, Utilization, Environmental Effects, 40, 2079–2096.