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EVALUATION OF OLIVE CAKE MANAGEMENT OPTIONS IN JORDAN USING RAPID IMPACT ASSESSMENT MATRIX

Abstract: This study evaluates different options for the valorisation of olive cake waste in Jordan, focusing on direct combustion, gasification, and composting. Physical/chemical, biological/ecological, sociological/cultural, and economic/operational aspects of each option are assessed using the Rapid Impact Assessment Matrix (RIAM) procedure. The findings indicate that composting of olive cake emerges as the most favourable option, offering positive impacts on soil quality, minimal environmental and social risks, and economic benefits through job creation and value-added products. Gasification and direct combustion also show potential but may require further consideration of local context and stakeholder preferences. Overall, the study provides valuable insights for decision-makers in selecting the most suitable olive cake valorisation option in Jordan.

Keywords: olive cake, RIAM, gasification, composting, solid waste management, EIA

Introduction

Olive oil is an important agri-food system in the Mediterranean area, accounting for 87 % of the 11.5 million hectares allocated to olive trees globally, with 86.6 % committed to olive oil production. With Spain, Italy, and Greece accounting for nearly 66 % of worldwide output, the European Union is the world's largest producer, consumer, and exporter of olive oil [1].

In Jordan, the olive tree is one of the most important trees in the country's fruit tree sector, as well as in the national economy. In 2021, the cultivated area with olive trees was around 57.2 thousand hectares, with approximately nine million bearing trees.

Figure 1 shows the annual production of olive fruits in Jordan from 2015 to 2024. In 2024, the olive crop production in Jordan was approximately 220.7 thousand tonnes (tonne = 10^6 g = Mg). About 25.8 % of the olive crop in Jordan is produced in Irbid city, while 13.2 %, 18 % and 4 % of the olive crop are produced in Amman, Mafraq and Karak respectively.

About 70 % of olive mills, which number around 140 mills in Jordan, discard the olive remnants such as olive cake (known locally as jift) and olive wastewater (known locally as

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zibar) [2, 3]. In the last six years, the average annual olive cake production is about 43 thousand tonnes (43 Gg) [4]. This implies the importance of getting rid of olive leftovers rapidly due to the environmental impact it causes in nearby areas. Citizens living near olive mills express their displeasure with the accumulation of olive cake in front of the olive mills. According to the regulations of the Ministry of Environment, olive mills have three months following the season to handle the olive mill waste in the mills' yards, which is a short period according to the olive mill owners. The majority of municipal landfills in Jordan are not permitted to accept such waste since olive cake is categorised as hazardous waste, which would be harmful to the environment when mixed with soil. Unfortunately, some of the olive mills are getting rid of the olive mill waste through illegal dumping. There are frequently several reported cases of olive mills unloading wet olive cake into rainwater streams [5].

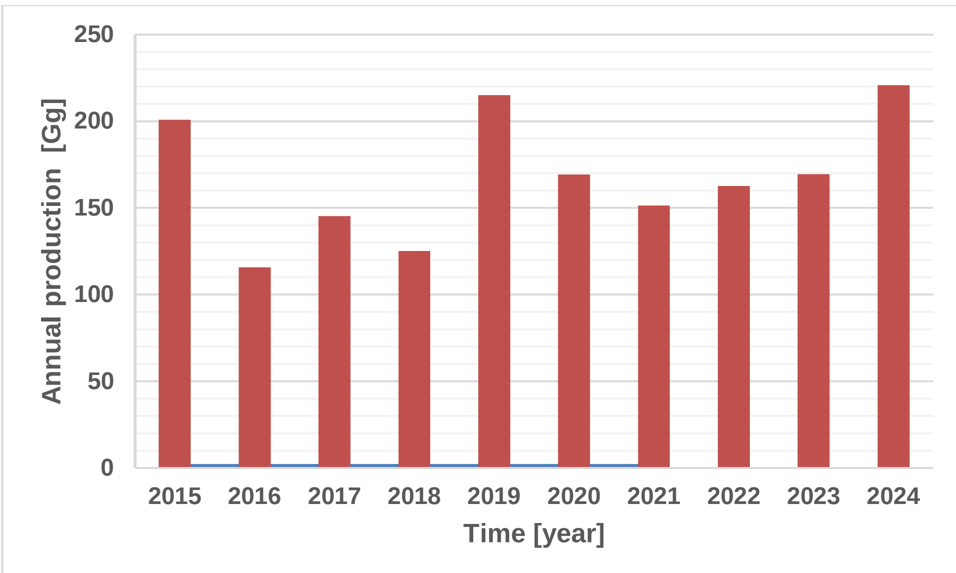

Fig. 1. Annual olive crop production in Jordan

Olive cake is difficult to manage because it is generated in large quantities on a seasonal basis and in a short period of time [6]. It is phytotoxic and has significant polluting properties, and has serious environmental impacts if improperly disposed of [7, 8].

While environmental experts warn about the influence of olive cake and olive wastewater on the environment, ground water, and public health, others argue that these wastes can be exploited to produce energy and valuable products, resulting in economic benefits [9]. In Jordan, olive cake handling options involves producing briquettes as a solid fuel for home heating at a price of 70-80 JOD/ton. The production of briquette from olive cake turns it into a product and a commodity, providing a low-cost way of heating for citizens with limited income. With an energy density of 23 MJ/kg, olive cake is a potential renewable energy source [10]. According to Al-Widyan and Al-Jalil [11], olive waste briquettes have a density that is more than double that of the original olive husk. Pelletising is another way to manage the olive cake waste. Pellets produced from olive cake can be used in a broader range of applications. Pelleting olive cake provides advantages in terms of higher bulk density and, consequently, higher heating value per mass unit. It also makes handling and transportation easier [12]. Olive cake pellets are now produced on a commercial scale and marketed in Europe as a viable energy source [13].

Pyrolysis is a thermochemical process to convert olive cake into various products. The pyrolysis process produces biofuel, which has a variety of commercial and industrial applications [14, 15]. The gaseous product can be used to fuel gas engines, boilers, and steam generators. The solid product can be used in combustion applications as a solid fuel. The liquid product can be refined to several important chemicals and utilised as a liquid fuel for engines and boilers [9, 16, 17]. Technologies for thermochemical conversion, like pyrolysis, might be highly important in this situation since they not only increase energy density but also significantly reduce volume, making storage and transportation more easier [18, 19].

Biomass gasification has been identified as a feasible technology for producing renewable hydrogen [20, 21]. Gasification converts solid biomass into synthetic gas (also known as "syngas"), which is a mixture of CO and H_2. Syngas is used to produce important different chemicals as well as synthetic fuels [22]. Gasification of olive cake offers a practical and alluring way to increase energy efficiency, enhance environmental and economic sustainability, diversify into new business models, and foster a circular economy [23].

Anaerobic digestion of olive cake can produce biogas and partially stabilised organic matter. Biogas can be utilised to generate electricity, and organic matter can be used to improve soil quality [24-26]. The anaerobic digestion of olive cake may be regarded a green solution with high potential for reducing greenhouse gas (GHG) emissions, and it plays an important role in renewable energy production by contributing to the closure of organic matter cycles from a circular economy standpoint [27, 28].

Composting is a cost-effective solution to olive cake problem, and its application to soil might be considered an acceptable method of improving soil fertility and plant growth, primarily by influencing its physical and chemical properties [29]. Olive cake can be composted with other feedstocks in different ratios and combinations, such as manure and olive leaves or straw [30].

Other options for olive cake valorisation involve drying and second extraction of oil, production of animal feeds and enzymes, production of sorbent material for the treatment of aqueous solutions and its application to agricultural soils to strengthen and extend the sorption of insecticides and herbicides to lessen the danger of groundwater pollution [1, 22].

Among the applications that have been researched is the use of olive cake as a partial substitute in lamb feeding mixes. The effect of partial replacement of barley grains by olive cake in lambs feeding mixes was beneficial in terms of improving the performance, nutrient digestibility and blood metabolites of Awassi lambs [30]. In addition, the economics of employing olive cake may be detected by the reduction in feed cost and the gross returns on animal products such as meat and milk. Recent studies have brought attention to an emerging trend: the utilisation of olive waste as a resource for producing bioplastics and biofertilisers [32, 33].

Reported investigations for olive cake valorisation in Jordan include the manufacture of sorbent material for the treatment of aqueous solutions [34, 35], bioadsorbent for the purification of biodiesel [36], usage as a soil amendment, particularly in soils low in organic matter, such as arid and semi-arid regions [37], compost production [38-40], bio-fuel production via pyrolysis [9], and the production of animal feed for the poultry industry [41].

The best practice for olive cake valorisation must include a comprehensive review of the project's technical, environmental, and socioeconomic implications. Environmental impact assessment (EIA) studies forecast the environmental impact of a proposed development project. EIA ensures that possible problems are identified and addressed early in the project planning and design process. The establishment of an EIA system is critical for conforming socioeconomic development projects to environmental safety and, as a result, ensuring long-term economic growth [42]. Rapid impact assessment (RIAM) is a tool for organising, analysing, and presenting the findings of a comprehensive EIA [43]. The RIAM model is used to compare various projects based on their negative and positive outcomes [44, 45].

The aim of this research is to evaluate the environmental impacts associated with the utilisation of olive cake through gasification, combustion, and composting methods, by achieving two objectives:

- Identify and address possible environmental problems early in the planning and design stages of olive cake valorisation projects.
- Assess both the negative and positive outcomes of gasification, combustion, and composting methods for olive cake valorisation, aiming to provide insights into the most environmentally sustainable approach for its utilisation.

RIAM methodology

Based on the scaling criterion, the RIAM approach is employed for rapid environmental impact assessment. For each scenario, quantitative scores are established. The activities included in the proposed olive cake utilisation methods are scored against each particular environmental aspect.

Four environmental aspects are assessed based on the RIAM methodology. These environmental aspects are: physical/chemical components (PC), biological/ecological component (BE), social/cultural components (SC), and economic/operational component (EO). The PC components refer to the natural and chemical characteristics of the environment, such as air quality, water quality, soil properties, noise levels, and climate conditions. They focus on how a project or activity affects the physical environment and chemical balance. The BE components involve the effects on living organisms and ecosystems, including vegetation, wildlife, habitats, biodiversity, and ecological relationships. They assess whether the project causes habitat loss, species disturbance, or changes in ecological processes. The SC components cover the impact on human communities, lifestyles, heritage, traditions, and cultural assets. They consider factors like population health, social well-being, community structure, cultural identity, and historical or archaeological sites. The EO components relate to economic activities, employment opportunities, infrastructure development, and operational aspects of the project. They assess how the project influences local or regional economies, resource utilisation, and sustainability of operations.

The environmental aspects are assessed based on five criteria, namely: importance of condition (X_1), magnitude of change/effect (X_2), permanence (Y_1), reversibility (Y_2), and cumulative (Y_3). In the RIAM methodology, the five standard criteria focus on the significance, scale, and persistence of impacts, but do not explicitly account for the likelihood or probability of the impact occurring. In RIAM, it is generally assumed that the conditions being assessed are likely or certain to occur based on project activities.

To provide a legal and regulatory context for our RIAM assessment, relevant Jordanian national legislation and environmental standards regarding the handling, utilisation, and disposal of olive cake were considered. The Waste Management Framework Law No. 16 of 2020 [46] establishes the overall framework for waste management in Jordan, including reduction, reuse, recycling, treatment, and safe disposal of various types of waste, such as agricultural by-products. In addition, regulations governing the disposal of olive mill wastewater ("zibar") require that it be transported to designated landfills under monitoring by the Environmental Police Directorate, as improper disposal can cause significant environmental impacts. Previous studies have also emphasised the need for appropriate legislation to regulate the application of untreated olive mill wastewater to soil, ensuring environmentally safe practices and promoting sustainable utilisation of olive by-products. Incorporating these references strengthens the policy relevance of our findings and situates the RIAM assessment within the framework of Jordanian environmental regulations.

A set of straightforward formulas is utilised to assess the value assigned to each criterion category, wherein the individual component scores are determined based on well-defined criteria, providing a quantifiable measure of the anticipated impact from each component. In category (X), the scoring system involves a simple multiplication of the scores allocated to each criterion. This approach ensures that the significance of each score is represented and mitigates the possibility of identical results for different conditions that could arise from a mere summation of scores. Conversely, in category (Y), the scores assigned to each criterion are aggregated to yield a single sum. This method eliminates the influence of individual value scores on the overall score while still acknowledging the collective importance of all values in category (Y). Subsequently, the product of category (X) scores is multiplied by the sum of category (Y) scores to derive the environmental score (ES) for the condition.

The mathematical representation of the aforementioned process is as follows [47]:

$$X_1 * X_2 = X_T \tag{1}$$

$$Y_1 + Y_2 + Y_3 = Y_T \tag{2}$$

$$ES = X_T * Y_T \tag{3}$$

ES signifies the environmental score for the condition. Once the environmental score "ES" is calculated, it is then converted into a range band. A range band is a categorical scale that groups the ES values into qualitative classes (e.g., major positive, moderate positive, minor negative). This helps in understanding the magnitude and direction of environmental impacts.

Table 1 gives the scores for each individual aspect to be determined using the assessment criterion proposed by Pastakia and Jensen [43].

Table 1

Scores for each individual aspect using the assessment criterion [43]

Criteria	Scale	Description
X_1: Importance of condition	4	Importance to national/international interest
	3	Importance to regional/national interest
	2	Importance to areas immediately outside the local conditions
	1	Importance only to the local conditions
	0	No importance
X_2: Magnitude of change/effect	+3	Major positive benefit
	+2	Significant improvement in status quo
	+1	Improvement in status quo
	0	No change in status quo
	−1	Negative change in status quo
	−2	Significant negative benefit or change
	−3	Major disbenefit or change
Y_1: Permanence	1	No change/not applicable
	2	Temporary
	3	Permanent
Y_2: Reversibility	1	No change/not applicable
	2	Temporary
	3	Permanent
Y_3: Cumulative	1	No change/not applicable
	2	Temporary
	3	Permanent

Table 2 displays the environmental scores and the range bands used in RIAM.

Table 2

Conversion of environmental scores to range bands [44]

Environmental score (ES)	Range bands (RB)	Range value (RV)	Description of range value
+72 to +108	+E	5	Major positive change/impacts
+36 to +71	+D	4	Significant positive change/impacts
+19 to + 35	+C	3	Moderately positive change/impacts
+10 to +18	+B	2	Positive change/impacts
+1 to +9	+A	1	Slightly positive change/impacts
0	N	0	No change/status quo/not applicable
–1 to –9	–A	–1	Slightly negative change/impacts
–10 to –18	–B	–2	Negative change/impacts
–19 to –35	–C	–3	Moderately negative change/impacts
–36 to –71	–D	–4	Significant negative change/impacts
–71 to –108	–E	–5	Major negative change/impacts

The implementation of RIAM requires a specialised assessment of environmental factors, typically delineated through a scoping process. The methodology for determining the most significant issues to be evaluated within each environmental component of concern involved a comprehensive review of existing literature, research articles, and reports related to the environmental components of interest. Subject matter experts in the fields of environmental engineering, chemical engineering, ecology, sociology, and economics are engaged to gather insights and identify key issues within each environmental component. Stakeholders, including local communities, government agencies, environmental organisations, and industry representatives, are consulted to understand their perspectives and concerns regarding environmental issues.

Based on the aforementioned methodology, the following significant issues are decided to be evaluated within each environmental component of concern:

Physical/chemical (PC) component:

- Air quality: assessing levels of pollutants such as particulate matter, and harmful gases.
- Water quality: investigating the presence of contaminants like, heavy metals, and hydrocarbons in water bodies.
- Soil contamination: investigating the presence of contaminants like, heavy metals, and hydrocarbons in soil.
- Noise pollution: evaluating the intensity, frequency, and duration of noise pollution from various sources, including transportation, industrial activities, construction sites, and recreational activities.

Biological/ecological (BE) component:

- Impacts on animals: assessing the direct and indirect effects of environmental changes, such as habitat loss, pollution, and climate change, on animal populations, behaviour, and physiology.
- Impacts on plants: evaluating the consequences of environmental disturbances on plant species richness, abundance, distribution, and community composition, including changes in plant physiology and phenology.
- Impact of anthropogenic activities, such as urbanisation, industrial development, and infrastructure projects, on ecosystems.
- Land degradation: evaluating the deterioration of the quality and productivity of land resources.

Sociological/cultural (SC) component:

- Community health and well-being: assessing the impact of environmental factors on public health and quality of life.
- Social equity: examining the distribution of environmental benefits and burdens among different socioeconomic groups.
- Environmental justice: addressing disparities in access to clean air, water, and green spaces.

Economic/operational (EO) component:

- Job creation and income generation: estimating the potential economic benefits of environmentally sustainable practices, including the creation of jobs and opportunities for local businesses.
- Value-added products and markets: exploring opportunities for adding value to natural resources through innovative processing techniques and accessing niche markets for sustainable products.
- Sustainable resource management: analysing the economic viability of practices that promote resource conservation and renewable energy.

Three options for olive cake valorisation, namely direct combustion, gasification, and composting, are evaluated using the RIAM procedure. In this study, for each valorisation route (direct combustion, gasification, and composting), we considered only one representative set of conditions - the one that has been reported, studied, or most widely applied under similar conditions in Jordan. This approach ensures that the comparison reflects realistic and practical scenarios rather than hypothetical cases. The RIAM scores were then calculated for these representative conditions to compare the three options consistently.

Scoring for each individual aspect is determined according to the criteria outlined in Table 1. Professionals in the fields of chemical engineering, environmental engineering, ecology, economics, and sociology are engaged in the scoring process. Forms are prepared and distributed to these experts to fill out, after which they are returned for analysis. The reported results for each aspect represent the answer with the highest frequency, providing a comprehensive evaluation of each valorisation option. The experts involved include professors and researchers from Jordanian universities with PhDs and MScs in their respective fields, as well as senior professionals from governmental and regulatory agencies. Their academic qualifications and professional experience ensure that the scoring reflects informed and qualified judgments.

Results and discussion

Table 3 displays the RIAM outcomes concerning the utilisation of olive cake through direct combustion. The table presents the environmental score for each component alongside its corresponding impact.

Table 3

RIAM results concerning option 1: direct combustion of olive cake

Environmental component	X_1	X_2	Y_1	Y_2	Y_3	X_T	X_T	*ES*	*RV*	**Impact/Change**
PC component:										
Air quality	1	–2	3	2	3	–2	8	–16	–2	Negative change/impacts
Water quality	2	0	1	1	1	0	3	0	0	No change/status quo/not applicable
Soil contamination	1	–1	1	1	1	–1	3	–3	–1	Slightly negative change/impacts
Noise pollution	0	0	1	1	1	0	3	0	0	No change/status quo/not applicable
BE component:										
Impacts on animals	0	0	1	1	1	0	3	0	0	No change/status quo/not applicable
Impacts on plants	0	0	1	1	1	0	3	0	0	No change/status quo/not applicable
Impact of anthropogenic activities on ecosystems	1	–1	3	2	3	–1	8	–8	–1	Slightly negative change/impacts
Land degradation	1	0	1	1	1	0	3	0	0	No change/status quo/not applicable
SC component:										
Community health and well-being	1	1	3	2	3	1	8	8	1	Slightly positive change/impacts
Social equity	1	1	3	2	2	1	7	7	1	Slightly positive change/impacts
Environmental justice	1	1	3	2	2	1	7	7	1	Slightly positive change/impacts
EO component:										
Job creation and income generation	1	1	3	2	2	1	7	7	1	Slightly positive change/impacts
Value-added products and markets	2	1	3	2	2	2	7	14	2	Positive change/impacts
Sustainable resource management	2	1	3	2	2	2	7	14	2	Positive change/impacts

Regarding the PC component, option 1 (direct combustion of olive cake) shows no impact on noise pollution and water quality. There is a slightly negative impact on soil pollution, indicating a minor adverse change. During the combustion process, certain compounds released as byproducts may infiltrate the soil, potentially leading to contamination. This can include ash deposition containing heavy metals or other pollutants, which may negatively impact soil quality and fertility [48].

The results indicate negative impact on air quality, indicating a more significant adverse change. Direct combustion generates emissions such as particulate matter, nitrogen oxides, sulphur dioxide, and volatile organic compounds. These pollutants can contribute to air pollution, leading to respiratory issues, smog formation, and other adverse health effects. Additionally, incomplete combustion may result in the release of harmful substances into the atmosphere [49].

In the BE component, option 1 shows no change in the status quo for animals, plants, and land degradation. However, there is a slightly negative impact of anthropogenic activities on ecosystems. The slightly negative impact of anthropogenic activities on ecosystems indicates that other human-induced factors, such as habitat destruction or pollution from surrounding activities, may contribute to detrimental effects on ecosystem health. Therefore, while the direct combustion of olive cake may not directly impact certain ecological components, broader anthropogenic influences on ecosystems should still be considered in environmental assessments.

In the SC component, the RIAM results indicated a slightly positive change or impact for community health and well-being, social equity, and environmental justice concerning the option of direct combustion of olive cake. The slight positive change in community well-being suggests that there are some beneficial effects associated with the direct combustion of olive cake. The combustion process leads to the reduction of waste and the generation of energy that benefits the community, thereby, contributing to improved overall well-being. The slight positive impact on social equity implies that the direct combustion of olive cake contributes to a more equitable distribution of environmental benefits and burdens among different socioeconomic groups. For instance, the implementation of this option leads to improved access to energy, and reduced environmental degradation in marginalised communities, which could help address existing inequalities and promote social justice. The slight positive change in environmental justice indicates that the option of direct combustion of olive cake leads to fairer distribution of environmental benefits and burdens across communities. This could involve ensuring that environmental risks and benefits are equitably distributed, and that vulnerable or disadvantaged populations are not disproportionately affected by negative environmental impacts.

In the EO component, the RIAM results for the option of direct combustion of olive cake indicate slightly positive change/impacts in job creation and income generation and positive change/impacts for both value-added products and markets and sustainable resource management. The slightly positive change in job creation and income generation suggests that the option of direct combustion of olive cake leads to the creation of employment opportunities and increased income levels within the community. This could be due to the establishment and operation of facilities for olive cake briquetting, which requires a workforce for operation and other related activities. Additionally, income may be generated through the sale of energy produced from olive cake combustion or through associated industries that utilise the by-products [50]. The positive change in value-added products and markets indicates that the direct combustion of olive cake has the potential to create value-added products and access new markets [51]. For example, the combustion process yield by-products such as ash or biochar, which can be utilised in various applications such as soil amendment, construction materials, or as raw materials for other industries. Expanding the market for these value-added products can contribute to economic growth and diversification. The positive change in sustainable resource management highlights the potential of direct combustion of olive cake to promote sustainable utilisation of resources. By utilising olive cake as a renewable energy source, the option supports the efficient management of agricultural residues and reduces dependency on fossil fuels [52]. The economic and operational benefits (heat, or employment) are important not just at the project site but also for the surrounding community or region where the project is implemented. Additionally, it may contribute to mitigating climate change by reducing greenhouse gas emissions associated with traditional waste disposal methods or fossil fuel combustion [53].

Table 4 displays the RIAM outcomes concerning the utilisation of olive cake through gasification. The table presents the environmental score for each component alongside its corresponding impact.

Table 4

RIAM results concerning option 2: gasification of olive cake

Environmental component	X_1	X_2	Y_1	Y_2	Y_3	X_T	X_T	ES	RV	**Impact/Change**
PC component:										
Air quality	1	–1	3	2	3	–1	8	–8	–1	Slightly negative change/impacts
Water quality	1	0	1	1	1	0	3	0	0	No change/status quo/not applicable
Soil contamination	0	0	1	1	1	0	3	0	0	No change/status quo/not applicable
Noise pollution	1	–1	1	1	1	–1	3	–3	–1	Slightly negative change/impacts
BE component:										
Impacts on animals	0	0	1	1	1	0	3	0	0	No change/status quo/not applicable
Impacts on plants	0	0	1	1	1	0	3	0	0	No change/status quo/not applicable
Impact of anthropogenic activities on ecosystems	1	–1	3	2	3	–1	8	–8	–1	Slightly negative change/impacts
Land degradation	1	0	1	1	1	0	3	0	0	No change/status quo/not applicable
SC component:										
Community health and well-being	1	1	3	2	3	1	8	8	1	Slightly positive change/impacts.
Social equity	1	1	3	2	1	1	6	6	1	Slightly positive change/impacts
Environmental justice	1	1	3	2	1	1	6	6	1	Slightly positive change/impacts
EO component:										
Job creation and income generation	1	1	3	2	2	1	7	7	1	Slightly positive change/impacts
Value-added products and markets	2	2	3	2	2	4	7	28	3	Moderately positive change/impacts
Sustainable resource management	2	1	3	2	2	2	7	14	2	Positive change/impacts

In the PC component, the RIAM results for the option of gasification of olive cake indicate slightly negative change/impacts in air quality and noise pollution and no change/status quo/not applicable for water and soil contamination. The slightly negative change in air quality and noise pollution suggests that gasification of olive cake may have some adverse effects on these environmental parameters. During the gasification process, emissions such as particulate matter, nitrogen oxides, and volatile organic compounds may be released into the atmosphere, contributing to air pollution [54]. Additionally, noise pollution may result from the operation of gasification equipment or associated activities. While the negative impacts may be relatively minor compared to other sources of pollution, they still warrant consideration and potential mitigation measures to minimise adverse effects on air quality and noise levels. The status quo or no change for water and soil contamination indicates that gasification of olive cake is not expected to directly impact these environmental components. Unlike combustion processes, gasification typically involves high-temperature conversion of organic materials into syngas without combustion, resulting in minimal production of ash or combustion by-products that could contaminate water or soil [55]. Therefore, water and soil contamination may not be relevant concerns for the gasification option, or the potential impacts may be negligible compared to other environmental considerations.

In the BE component, the RIAM results for the option of gasification of olive cake indicate no change/status quo on animals, plants and land. Nevertheless, gasification of olive cake may contribute to broader negative effects on ecosystems due to human activities. Gasification processes can generate emissions or by-products that may affect ecosystem health, such as air pollution or habitat disturbance [56]. While the negative impact may be relatively minor compared to other activities, it still warrants consideration and potential mitigation measures. Similar to animals and plants, the status quo or no change indicates that gasification of olive cake does not directly contribute to land degradation. This suggests that the gasification process does not involve significant land use changes or practices that would degrade soil quality or lead to erosion [57].

In the evaluation of olive cake gasification through the SC component of the RIAM, the findings indicate that there is a slightly positive change in the impact on community health and well-being, social equity, and environmental justice. The slightly positive change in community health and well-being implies that the gasification of olive cake could potentially contribute to improving the overall health and well-being of the community. This could be due to reduced reliance on traditional energy sources that may produce harmful emissions, leading to better air quality and a healthier living environment. The slight positive change in social equity suggests that gasification of olive cake may promote fairness and equality within the community. By providing access to cleaner energy sources and potentially creating employment opportunities, the option could help reduce disparities and improve social cohesion. The slightly positive change in environmental justice indicates that the gasification of olive cake may contribute to addressing environmental issues in a fair and equitable manner. This could involve ensuring that the benefits and burdens of the process are distributed fairly among all members of society, regardless of socio-economic status or other factors.

In the evaluation of olive cake gasification through the Economic/Operational (EO) component of the RIAM, the findings indicate that there is a slightly positive change in the impact on job creation and income generation. The gasification of olive cake leads to some positive outcomes in terms of employment opportunities and economic prosperity within the community [58]. This could be through direct employment in the gasification process or indirect employment in related industries and services, leading to economic growth and poverty alleviation. There is a moderately positive change in the impact on value-added products and markets. The gasification of olive cake has the potential to create value-added products [59] and open up new markets, contributing to economic growth and diversification. By converting olive cake into valuable energy products or biofuels, the process could enhance economic competitiveness and stimulate investment in the region. There is a positive change in the impact on sustainable resource management. This suggests that gasification of olive cake may contribute to more sustainable use of resources, potentially leading to environmental benefits and long-term viability of the process [60]. The EO component in our RIAM assessment focused on value-added products and market potential. Financial aspects such as initial cost, payback period, or benefits/cost ratio were not included, as the scope of the assessment was to evaluate environmental and operational significance rather than detailed economic feasibility.

Table 5 displays the RIAM outcomes concerning the utilisation of olive cake through composting. The table presents the environmental score for each component alongside its corresponding impact.

Table 5

RIAM results concerning option 3: composting of olive cake

Environmental component	X_1	X_2	Y_1	Y_2	Y_3	X_T	X_T	*ES*	*RV*	**Impact/change**
PC component:										
Air quality	1	–1	3	2	3	–1	8	–8	–1	Slightly negative change/impacts
Water quality	1	–1	3	1	3	–1	7	–7	–1	Slightly negative change/impacts
Soil contamination	1	2	3	1	3	2	7	14	2	Positive change/impacts
Noise pollution	0	0	1	1	1	0	3	0	0	No change/status quo/not applicable
BE component:										
Impacts on animals	1	1	3	1	3	1	7	7	1	Slightly positive change/impacts
Impacts on plants	1	2	3	1	3	2	7	14	2	Positive change/impacts
Impact of anthropogenic activities on ecosystems	1	1	3	2	3	1	8	8	1	Slightly positive change/impacts
Land degradation	1	2	3	1	3	2	7	14	2	Positive change/impacts
SC component:										
Community health and well-being	1	1	3	2	3	1	8	8	1	Slightly positive change/impacts
Social equity	1	1	3	2	1	1	6	6	1	Slightly positive change/impacts
Environmental justice	1	1	3	2	1	1	6	6	1	Slightly positive change/impacts
EO component:										
Job creation and income generation	2	1	3	2	2	2	7	14	2	Positive change/impacts
Value-added products and markets	2	2	3	2	2	4	7	28	3	Moderately positive change/impacts
Sustainable resource management	2	2	3	2	2	4	7	28	3	Moderately positive change/impacts

In the evaluation of composting of olive cake through the PC component of the RIAM, the findings indicate slightly negative change in air and water qualities. Composting of olive cake may result in some minor emissions that could affect air quality [61]. These emissions may include gases such as carbon dioxide or methane produced during the composting process. While these emissions are relatively minor compared to other sources of air pollution, they still warrant consideration and potential mitigation measures to minimise their impact. Composting of olive cake leads to some minor impacts on water quality, possibly through leachate runoff containing nutrients or organic matter [62]. Proper management practices, such as controlling runoff and managing composting sites, can help mitigate these impacts and protect water quality.

There is a positive change in soil contamination. The positive change in soil contamination indicates that composting of olive cake may have positive effects on soil quality. The addition of composted olive cake to soil can improve soil structure, fertility, and microbial activity, leading to healthier and more productive soils [63].

There is no change or status quo in the impact on noise pollution. This implies that composting of olive cake does not directly contribute to noise pollution, or that any noise generated during the process is negligible and does not warrant significant concern.

The slightly positive change in impacts on animals implies that composting of olive cake could potentially provide benefits for animal populations or habitats. This could include improved habitat quality, food availability, or other factors that support animal well-being. The positive change in impacts on plants suggests that composting of olive cake may have favourable effects on plant growth, diversity, or resilience [64]. Composted olive cake could serve as a nutrient-rich soil amendment, enhancing soil fertility and promoting healthier plant growth [65]. The slightly positive change in the impact of anthropogenic activities on ecosystems indicates that composting of olive cake may help offset some of the negative impacts of human activities on natural ecosystems. By recycling organic waste materials like olive cake through composting, the process could contribute to ecosystem restoration or conservation efforts. The positive change in the impact on land degradation suggests that composting of olive cake may play a role in preserving soil quality and preventing land degradation. Composted olive cake can improve soil structure, moisture retention, and nutrient levels, reducing erosion and enhancing the sustainability of agricultural or natural ecosystems.

There is a slightly positive change in the impact on community health and well-being, social equity, and environmental justice. This suggests that composting olive cake may have beneficial effects on these aspects of society. Composting olive cake can lead to the production of nutrient-rich compost, which can be used to enrich soil and support healthier plant growth. This may enhance access to fresh produce and green spaces, promoting physical and mental well-being among community members. The slight positive change in social equity suggests that composting olive cake may help promote fairness and equality within the community. By providing opportunities for participation in composting initiatives and access to nutrient-rich soil amendments, the process could contribute to bridging socioeconomic disparities and fostering social inclusion. This may lead to a more equitable distribution of environmental benefits and resources among community members. The slightly positive change in environmental justice indicates that composting olive cake may contribute to addressing environmental issues in a fair and equitable manner. By diverting organic waste from landfills and reducing greenhouse gas emissions, composting can help mitigate environmental pollution and climate change impacts. This may benefit marginalised communities disproportionately affected by environmental hazards, promoting environmental justice and equity in resource allocation and management.

The positive change in job creation and income generation implies that composting olive cake could result in the creation of employment opportunities and income streams for individuals involved in the composting process, as well as those engaged in related activities such as sales and distribution of compost products [66]. This could contribute to economic development and poverty alleviation in the community. The moderately positive change in value-added products and markets suggests that composting olive cake has the potential to add value to the original waste material and create marketable compost products [67]. These products could be used in various applications such as agriculture, landscaping, and soil remediation, thereby opening up new market opportunities and increasing revenue streams for businesses involved in the composting industry. The moderately positive change in sustainable resource management indicates that composting olive cake may help promote more efficient and sustainable use of resources [68]. By recycling olive cake into nutrient-rich compost, the process can reduce the need for chemical fertilisers and improve soil health, leading to enhanced agricultural productivity and environmental conservation. This aligns with principles of sustainable resource management and contributes to the overall resilience of ecosystems and communities [69].

Comparative assessment of olive cake valorisation options

Overall, all three options for olive cake valorisation: direct combustion, gasification, and composting have distinct advantages and limitations across the physical/chemical, biological/ecological, sociological/cultural, and economic/operational components. The choice of the most suitable option depends on factors such as local conditions, resource availability, infrastructure, and stakeholder preferences. Previous studies have similarly highlighted that the best valorisation pathway varies depending on regional characteristics and intended outcomes [70-72].

Based on our RIAM assessment, composting of olive cake is recommended for Al-Karak Governorate, Jordan, because it provides: positive impacts on soil quality, minimal environmental and social impacts, and economic opportunities through job creation and value-added products.

These findings align with previous research showing that composting enhances soil fertility while being a feasible and low-impact option in regions with available land and agricultural activities. Further stakeholder consultation, feasibility studies, and implementation planning are recommended to ensure successful adoption and maximise benefits.

The gasification option may be more suitable in other regions of Jordan where there is demand for energy production and existing infrastructure for gasification. Areas with limited agricultural land or where composting logistics are challenging may benefit more from gasification, which allows for renewable energy recovery and the production of biochar [71]. Feasibility studies and stakeholder engagement would be necessary to identify the most suitable locations for implementing gasification.

Conclusion

This study highlights the potential for valorising olive cake waste in Jordan through different options such as direct combustion, gasification, and composting. While each option offers unique advantages and challenges, composting emerges as the most favourable choice due to its positive impacts on soil quality, minimal environmental and social risks, and economic benefits. However, gasification and direct combustion also present viable alternatives, particularly in regions with specific energy needs and infrastructure. Stakeholder consultation and further feasibility studies are recommended to determine the optimal olive cake valorisation option for each region in Jordan, ensuring sustainable waste management and maximising economic and environmental benefits.

Overall, this research contributes to advancing olive cake valorisation efforts in Jordan and informs decision-making processes in the field of waste management and renewable energy.

Future research in the field of olive cake valorisation in Jordan holds significant potential for addressing critical gaps and advancing knowledge in several key areas. Research focusing on the development and optimisation of novel technologies for olive cake valorisation, such as advanced gasification systems and integrated waste management approaches, can enhance efficiency, resource recovery, and environmental performance of olive cake valorisation processes. Research examining the policy and governance frameworks governing olive cake valorisation in Jordan can identify barriers, challenges, and opportunities for promoting sustainable waste management practices and renewable energy utilisation. Comparative studies of policy approaches in other regions can provide valuable lessons and insights for policymakers.

In addition to the findings presented, it is recommended that further EIA be conducted for olive cake valorisation projects in Jordan. Exploration of additional valorisation options, such as anaerobic digestion, advanced biochar production, or integration into circular economy frameworks, could provide complementary environmental, economic, and social benefits. Incorporating these approaches in future studies would help identify the most sustainable and context-appropriate solutions for olive cake management in different regions of Jordan.

Acknowledgements

The authors would like to express their sincere gratitude for the financial support provided by the Scientific Research and Innovation Support Fund/Higher Council for Science and Technology (formerly affiliated to Ministry of Higher Education and Scientific Research) (ENE/1/5/2018). This support was instrumental in facilitating the completion of this research project. The Deanship of Scientific Research at Mutah University is also acknowledged.

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