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Production and utilization aspects of waste cooking oil based biodiesel in Pakistan

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Abstract Excessive fuel demand thrusts the Pakistani government to import large volumes of fuel from foreign sources, creating adverse effects on the country's economy. Therefore, exploring an alternative to fossil fuels is unavoidable. The option of environmentally friendly fuel like biodiesel produced from indigenous waste is an additional bonus for the populous developing country like Pakistan where likelihood of waste generation is huge. There exists a potential option for sustainable biodiesel production utilizing excessive waste cooking oil available in the country which otherwise is an ecological burden. The present work is focused to sturdily vindicate the appropriateness of waste cooking oil-based biodiesel generation and utilization in Pakistan through SWOT-AHP, TOWS and PESTLE analysis. The prioritization of SWOT through AHP in view of experts' perception displayed the strengths and opportunities in highest group priority values (Strengths: 0.51, Opportunities: 0.29). Furthermore, TOWS analysis suggests promising strategies for the sustainable implementation of commercial aspect of waste oil-based biodiesel in Pakistan. Political, Economic, Social, Technological, Legal and Environmental (PESTLE) analysis favors the strengths and opportunities factors of SWOT and TOWS strategies for the application of waste cooking oil based biodiesel in country. At the end, regional recommendations have been provided for the implementation of biodiesel production scenario in country.

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1. Introduction

The inevitable profusion of rising demand over declining supplies of earth's reserves is a vital issue and has gained a great consideration over the past several decades. Fossil fuels remained the core energy stream since antiquity. Due to hasty growth in the worldwide populace and industrialization, these fossil fuel reserves are diminishing exceptionally. This mash on the energy has provoked the global research community to probe some alternative energy sources such as biofuels [1–3]. In 2018, global biofuel production has raised up 7% from 2017 and reached 152 billion liters with 3% of the global fuels for highway transportation. As per International Energy Agency (IEA) target, biofuels must meet over one fourth of global need for transportation fuels by 2050 to lessen reliance on petroleum derived fuels. Conversely, the biofuels production and consumption are not advancing at desired level to fulfill the IEA's sustainable development target. The worldwide biofuel production has to increase by 10% per annum from 2020 to 2030 to attain IEA's goal. The annual expected growth is 3% only [4].

Amid numerous renewable fuels, biodiesel has picked up worldwide prominence because of its neat burning and renewability [5,6]. It is a widely held view that biodiesel mixed with conventional diesel effectively lessens the discharge of carbon monoxide, particulate matter and hydrocarbons to a significant degree with slight loss in power [7]. In addition, biodiesel remains ahead in terms of energy yield among other renewable fuels [8]. In the US, above 80% of commercial transportation utilizes diesel fuel. The evolving US biodiesel trade is valued to have expanded 200% from 2004 to 2005. The US monthly biodiesel production since 2018 is indicated in Fig. 1 [9].

In France, year 2017 indicated peak consumption of biodiesel equivalent to 2,798 Ktoe. This value is about 770 Ktoe greater than the value of the fuel consumed in 2010 [10]. One fifth of 11 million tons biodiesel consumed yearly in the Europe is delivered by the Avril Group under the brand Diester, a leading European biodiesel producer [11]. According to the OECD FAO Agricultural Outlook (2019 2028), the European Union is anticipated to persist its position in the major biodiesel producers. As per report, 12.9 billion liters of biodiesel will expectedly be produced by 2027, down from 13.5 billion liters in 2017 and 14 billion liters in 2020 when the renewable energy target (RED) target is aimed to be met [12].

The worldwide biodiesel production is estimated to reach at the value of 39.3 billion liters by 2027 in comparison with 9% raise from the value in 2017. The biodiesel production patterns will be greatly influenced by the policies rather than market forces. As mentioned, the selection of feedstock to produce biodiesel will remain the vegetable oil. Moreover, waste oil and tallow as biodiesel feedstock will keep on playing a major role in Europe and the United States [12].

In Pakistan, the utilization of fossil derived fuels remained significant in the production and transportation sectors troubling the country's economy and generating environmental problems. In 2018–19, transportation sector continued to be the major energy user in the country with energy consumption of over 77% among all sectors [13]. The fuels of major consumption such as gasoline and diesel ought to be replaced with renewable fuels such as bioethanol and biodiesel that can reasonably limit the dependence on fossil-derived fuels. In addition, the emission aspects of ethanol and waste cooking oil biodiesel in reactivity-controlled compression ignition mode have been successfully studied with reduced smoke and NO_x emissions [14].

Pakistan is an emerging country with a population of about 200 million individuals [15]. In 2019, the country's total primary energy consumption (TPEC) was 3.56 EJ (exajoules) (Fig. 2) [16] and fuel wise primary energy consumption is shown in Fig. 3. Oil and gas resources played significant role in accomplishing the energy requirements of the country. The native oil reseves are not sufficient to fulfill the energy need of developing nation requiring oil import from Arab countries, especially from Saudi Arabia. In 2019, the production of home-grown crude oil remained 24.6 million barrels compared to 21.8 million barrels in the previous year [13]. On the other side, the imported quantity of crude oil in 2019 remained 6.6 million tones amount to US $ 3.4 billion in

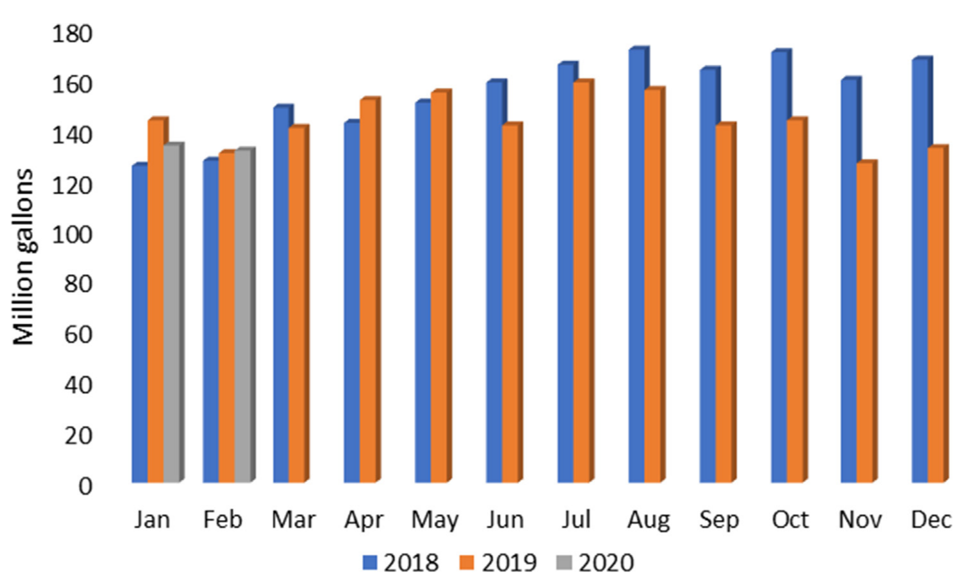

Fig. 1 US monthly biodiesel production (2018–2020).

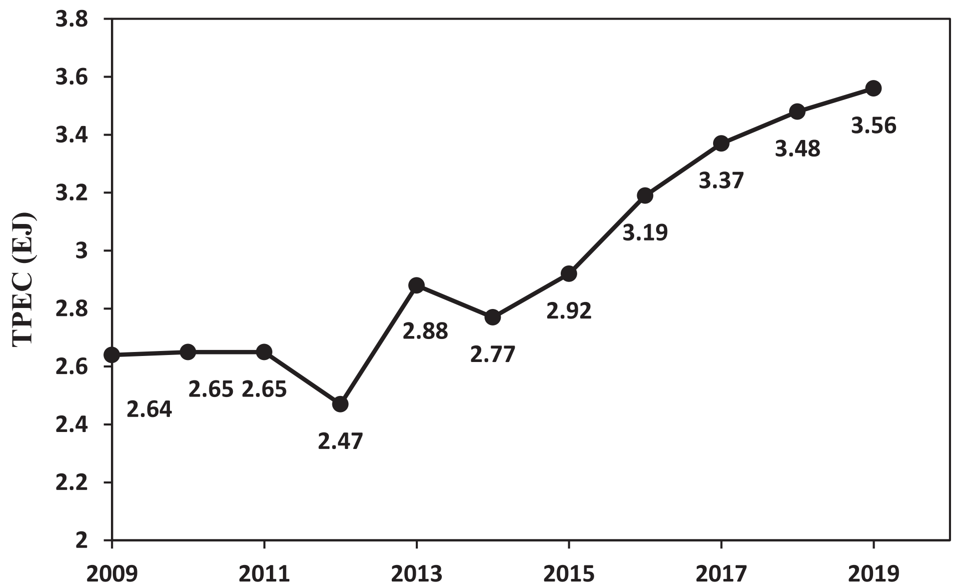

Fig. 2 Total primary energy consumption of Pakistan (2009–2019).

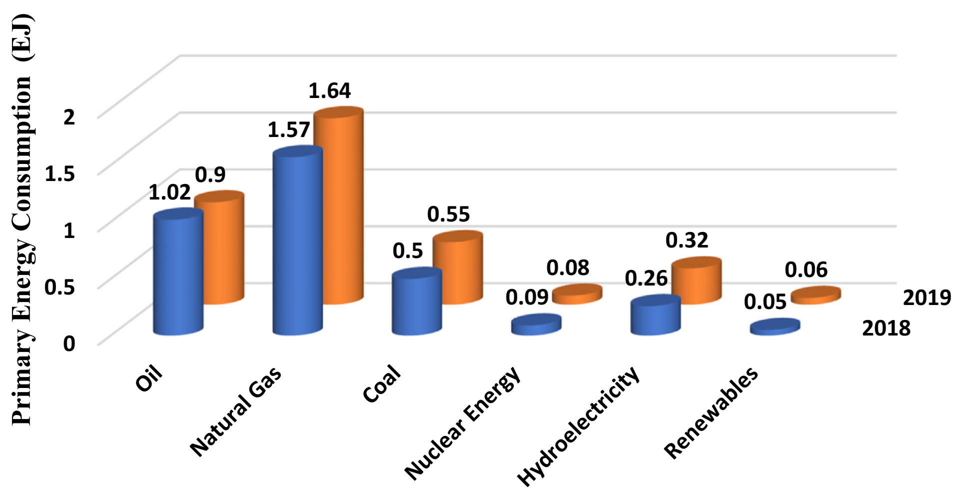

Fig. 3 Pakistan's fuel wise primary energy consumption (2018–19).

comparison with the measure of 7.8 million tones amount to US $ 2.9 billion in the previous year. The reduction in imported quantity was mostly due to surge in international prices. The overdue payment on imported oil from Saudi Arabia will provide an ease to the government on balance of payments. Transport and power sectors are the two notable users of oil. In 2019, transport sector exposed the share of oil consumption up to 77 from 56 percent during the last year, while share of oil consumption in power division decreased to 14 percent in 2019 which was 25 percent during the last year. Primarily, gas being the economical source, resulted in shifting power sector from oil to gas [13].

On the other side, the scenario of edible oil production and import will also come into point of discussion while considering waste oils as feedstock for power generation. The major oilseed crops produced in Pakistan are sunflower, canola, rapeseed/mustard and cotton. During 2017–18, 1.944 million tons of edible oil amount to US$ 1.453 billion has been imported while local generation of edible oil during the same period is provisionally valued at 0.503 million tones. The tentatively measured value of overall accessibility of edible oil from all sources was 2.447 million tons during 2017–18 [17]. Therefore, the huge oil consumption likewise generates a substantial quantity of WCO that can be potentially used for biodiesel generation in country. As per our previous investigation [18], 960 million kilograms of WCO is annually available in Pakistan. Moreover, it has been reported that WCO based biodiesel production can scale back the direct production expenses in comparison with other raw materials in our neighboring country, India [19].

In actual fact, the country's transportation division is solely dependent on conventional fuels with no approachability for renewable fuels in this zone. Diesel and gasoline are the main POL items employed as the part of country's transportation. Apart from the fossil fuels depletion problems, another foremost dilemma accompanying with the combustion of conventional fuels is greenhouse gas emissions and environmental issues. Undeniably, approximately 195.2 million tons of CO_2 in Pakistan was produced in 2018 with a prominent annual growth rate of 2.9% since 2007 [20] The BP energy outlook forecasted that the global emissions in 2035 would rise about double the value existed in 1990. Then again, nearly 7 million people per annum embrace death due to air contamination according to the statistics produced by the World Health Organization (WHO) [21,22]. Hence, utmost requirement is to probe alternative energy resources with the least environmental consequences.

The present research work is focused to vindicate the appropriateness of WCO based biodiesel production in Pakistan using SWOT-AHP analysis, TOWS analysis and PESTLE analysis. PESTLE was implemented for scenario development and SWOT and TOWS for their analysis of strategy design. In developing countries like Pakistan, these analyses may be quite helpful in shifting the conventional trend of energy generation toward biofuels.

2. Methodology

2.1. SWOT-AHP, TOWS and PESTLE analysis

The cautious strategic planning is a key component in local and regional development and structuring. A systematized planning scheme to weigh the strengths, weaknesses, opportunities and threats implicated in a business or project is termed as SWOT analysis [23].

The internal and external assessment measures are taken into account in SWOT analysis. The internal analysis is carried out to construe and focus the strengths and weaknesses of any type of strategic planning, while the evaluation of the connected opportunities and threats existing in the market is carried out through external analysis. It was principally established for business and marketing analysis objective later extensively implemented in many other fields for research aid including energy sector. Following are the components of SWOT analysis (see Fig. 4)

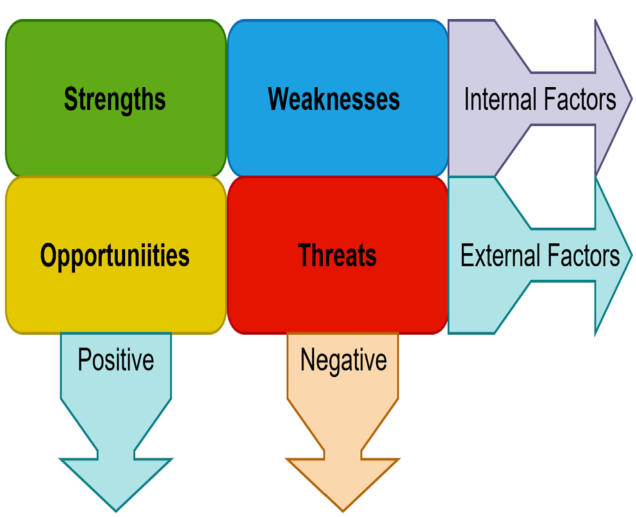

Fig. 4 SWOT matrix.

- Strengths are the features of any scheme that provide an advantage over others,
- Weaknesses are the features that keep the project at a relative hindrance,
- Opportunities are aspects the project could use to its benefits,
- Threats are the components in the scenario that could endanger the project.

The SWOT analysis was performed using data collected by biodiesel producers, literature means, the stratagem for the expansion of renewable energy sources along with legal acts and regulations. No SWOT analysis as per our knowledge, has previously undertaken before for the WCO based biodiesel production in Pakistan. The SWOT analysis in this paper reveals the potential suitability of utilizing waste for biodiesel production considering the current national situation of the country and international scenario of biofuels production.

Furthermore, quantification of SWOT analysis has been carried out by applying AHP analysis. Each factor in SWOT analysis is quantified based on its precedence for the respective concern. The experts are involved in AHP method to perform thought-provoking haggling between factors via pairwise comparisons in order to prioritize each factor [24]. This pairwise comparison transforms the importance of each factor into mathematical format, even if the original outcomes are incomparable. For evaluating the relative importance between factors, the allotted weights valued from 1 to 9, but were conferred as an ordinal scale of importance in the actual survey (1 = Equal; 3 = Moderate; 5 = Strong; 7 = Very Strong; 9 = Extreme) to simplify the task for respondents. Fig. 5 displays a comparative representation among three factors.

a_{ij} is denoted as the relative weightage of factor X_i with respect to factor X_j in a discrete SWOT group. The pairwise comparison matrix (Γ) can be generated using;

$$\Gamma = (aij) = \begin{bmatrix} X1/X1 & \cdots & X1/Xn \\ \vdots & \ddots & \vdots \\ Xn/X1 & \cdots & Xn/Xn \end{bmatrix}$$

$W = (\omega_1, \omega_2, \ldots, \omega_n)$ can be used to represent the relative priority of each factor in a specific SWOT group and is attained by scheming the normalized eigenvector of Γ corresponding to the Γ's Eigen-value λ_m, i.e.,

$$\Gamma W = \lambda_m W$$

In addition, the consistency of matrix Γ must be within limit of 10%. A is consistent if

$$a_{ij} = a_{ik} a_{kj}, \forall i, j, k = 1, 2, \ldots, n$$

If Γ is not consistent, a consistency index (CI) analysis may be performed to measure the consistency ratio (CR) using the following equation:

$$CI = (\lambda_m - n)/(n - 1)$$

$$CR = CI/RI$$

Whereas RI represents random index value. If the values of CI and CR are close to zero, it indicates that the consistency is good. If $CR \leq 0.1$, the consistency of A is acceptable [25].

In order carry out the AHP analysis, a group of experts including industrial representatives, researchers, feedstock

Sr.	A-wrt AHP priorities-or-B		How much important?
1	□ A	□ B	□ 1 □ 2 □ 3 □ 4 □ 5 □ 6 □ 7 □ 8 □ 9
2	□ A	□ C	□ 1 □ 2 □ 3 □ 4 □ 5 □ 6 □ 7 □ 8 □ 9
3	□ B	□ C	□ 1 □ 2 □ 3 □ 4 □ 5 □ 6 □ 7 □ 8 □ 9
1=Equal; 3=Moderate; 5=Strong; 7=Very Strong; 9=Extreme (2, 4, 6, 8 values in-between)			

Fig. 5 Pairwise comparison extract from questionnaire.

producers, government representatives and consumers are communicated individually via pair-wise factor comparison questionnaire for their valuable responses. Convenience sampling was carried out for data collection as it's uncomplicated, and economical. The received results were then compiled for overall opinion evaluation in terms of priority and the previously mentioned AHP method was applied through AHP-OS online system to calculate the factor priority within the SWOT group, group priority and overall priority of the factor [26]. The soundness of the data was checked through consistency ratio value that must be less than 10%. After finding the priority of each factor within the SWOT group, the factor with highest local priority is nominated from each group to denote the overall group of strengths, weaknesses, opportunities and threats. These four factors are then compared and their relative priorities are calculated termed as group priority. Then the overall priority of the factor within each group is obtained by the multiplication of factors local priorities with the group priority. The sum of the overall priority of the factor within each group should be 1. Priorities of the factors within SWOT groups and decision matrix calculations through the AHP-OS online system have been provided in the Appendix A.

On the other side, taking SWOT one step further leads to generate TOWS matrix. The objective of TOWS analysis is to identify strategies based on an earlier conducted SWOT analysis. Therefore, identified strengths, opportunities, weaknesses and threats are taken into account to develop strategies being reflected in the specific TOWS matrix [27,28]. Indeed, these strategies are designed by exploiting the strengths and opportunities as well as curtailing the weaknesses and threats of the respective stakeholders. TOWS matrix involves following components (see Fig. 6)

- **Maxi-maxi strategy (Strength-Opportunities):** policies that use strengths to exploit opportunities.
- **Maxi-mini strategy (Strength -Threats):** tactics that use strengths to lessen threats.
- **Mini-maxi strategy (Weaknesses-Opportunities):** policies that minimalize weaknesses by taking advantage of opportunities.
- **Mini-mini strategy (Weaknesses-Threats):** plans that minimalize weaknesses and prevent threats.

Fig. 6 TOWS matrix.

The overall model has been presented in Fig. 7. In the first step, detailed SWOT analysis is conducted taking inputs from internal and external environment. The major limitation associated with SWOT analysis is that it is only a qualitative approach for assessing factors. The significance of each factor in decision making cannot be measured quantitatively, therefore, it becomes problematic to evaluate the relative importance of factor in decision making. Therefore, in the second step, critical and summarized version of SWOT factors have been chosen and linked with AHP technique to obtain the quantitative importance of factors in decision making [24]. In the third step, the overall model SWOT-AHP-TOWS analysis has been adopted to improve decision making process and to develop strategies. This model enables the integration of analysis, recognizing the relative priorities of factors and strategy development [29,30].

The PESTLE analysis is quite useful to assess the external effects on the biofuel industry which control the dynamics shaping the enduring viability of the industry [31]. PESTLE relates to Political, Economic, Social, Technological, Legal, and Environmental aspects (Fig. 8). It gives an extensive picture of the overall environment of the biofuel industry mainly considering opportunities and threats. Therefore, this analysis helps out in determining the factors for the ecological, socioecological, economical and geopolitical sustainability features. It delivers the plan in association with the production technologies to analyze the pros and cons of the different production paths.

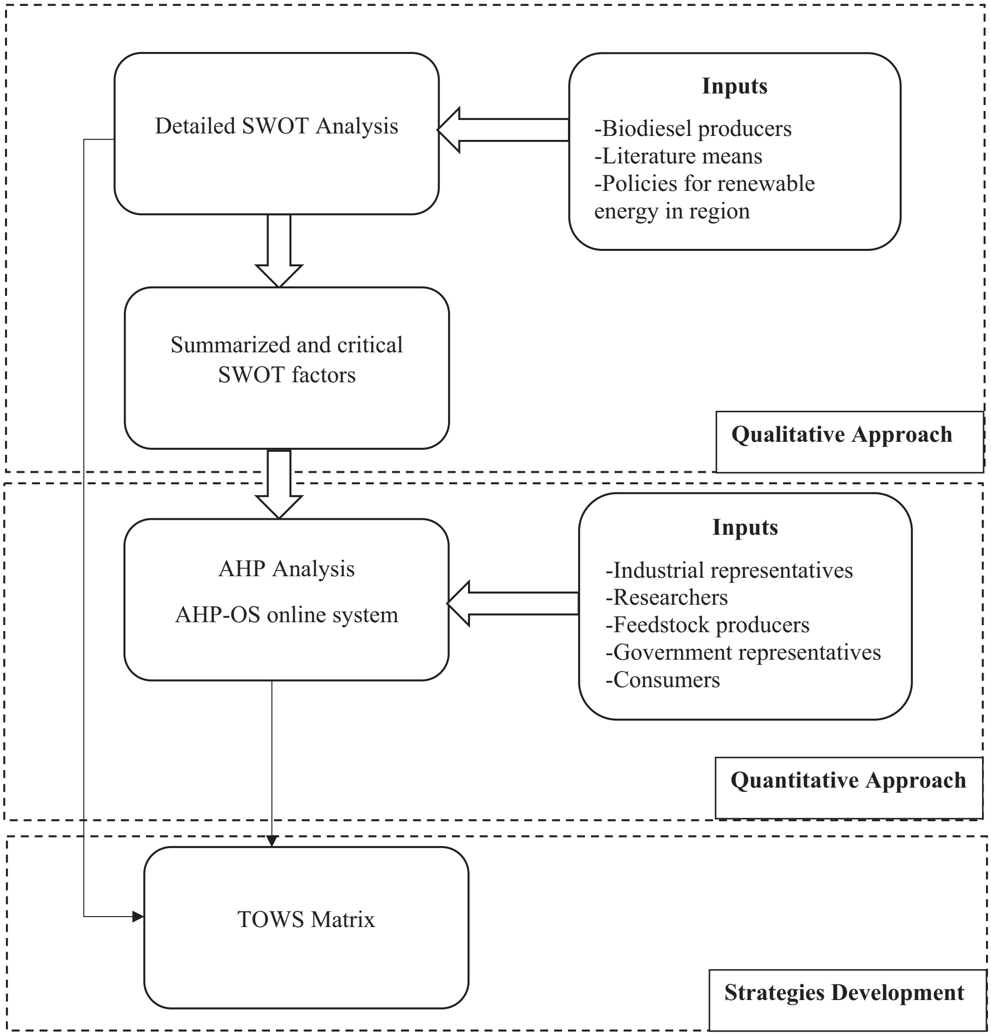

Fig. 7 SWOT-AHP-TOWS overall model.

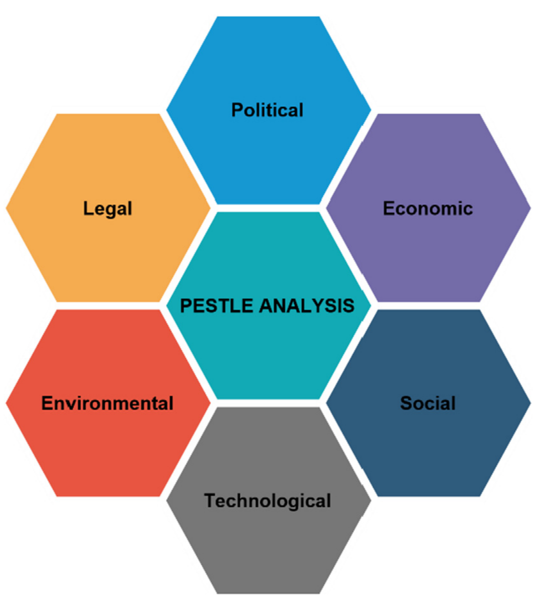

Fig. 8 PESTLE analysis.

3. Results and discussion

3.1. SWOT analysis

SWOT analysis for waste cooking oil-based biodiesel production in Pakistan has been provided in table 1. Strengths and weaknesses are to be determined considering major internal factors such as availability of raw material (WCO) in country, waste management issues, energy crisis, existing regulations and accessible WCO quality etc. Similarly, opportunities and threats are to be identified keeping in view the external aspects. Strengths and opportunities of analysis are considered to be the success factors whereas weaknesses and threats reflect failure parameters of SWOT analysis. The detailed analysis is mentioned below.

Pakistan is a developing country discerning to focus in renewable energy sector, therefore, the pressing priority is to line up existing energy sources which can be transformed into renewable fuels for technological and economic development of the country. While in view of energy substitutes, there are three main facets that acquire consideration including economic competitiveness, energy security, and environmental

Table 1 Detailed SWOT analysis for WCO based biodiesel production and consumption in Pakistann.

	Success factors		Failure factors
Strengths	**S1:** WCO based biodiesel production in Pakistan sustains food security as 0.96 million tons of WCO is yearly available in the country which can be potentially utilized for biodiesel production. Moreover, it does not clash with crops for land use [18] **S2:** WCO based biodiesel production can possibly meet the rising demand for energy security as dependence on limited fossil reserves will be minimized **S3:** Biodiesel is renewable in nature therefore it will play a significant role in minimizing CO_2 emissions **S4:** It will help in tackling waste management issues related to disposal of waste oils **S5:** It can be produced regionalized and thus boost rural economies. **S6:** The production of co-products provides additional income **S7:** Low cost local WCO based biodiesel production with existing matured technologies will reduce burden on national treasure in terms of diesel import **S8:** The country's regulatory authorities such as PSO and AEDB are associated in framing policies and attaining goals for biodiesel production **S9:** Biodiesel can be adjusted in existing fuel production and transportation framework**:** **S10:** Biodiesel blend with diesel is successfully workable **S11:** WCO based cheap biodiesel can be utilized in power generation to cope up with electricity crisis **S12:** No food vs fuel controversy exists in case of WCO based biodiesel production **S13:** Continuous improvement in technologies **S14:** Waste cooking oil is a reliable feedstock to produce FAME **S15:** Pakistan imports a large quantity of glycerol and glycerol water from Malaysia that otherwise can be produced locally [32]	**Weaknesses**	**W1:** Transesterification is commonly used for biodiesel production. Transesterification reaction can be assisted with acid, base or enzyme based catalysts depending on the unwanted items particularly water and free fatty acids present in WCO. **W2:** The WCO recovery rate is crucial in biodiesel production. A low WCO collection rate implies a shortage of feedbacks. This will not only obstruct the positiveness of biodiesel enterprises, but also drive against the mass production of biodiesel **W3:** The quality of WCO significantly influences the overall efficiency of biodiesel production process. Therefore, pretreated WCO is required for good quality biodiesel **W4:** Biodiesel is described by lower energy content per volume than fossil fuels. **W5:** Lacking of clear vision and constructive roadmap is not developed as yet. **W6:** Distinctive gap exists between R & D and commercialization **W7**: Engine performance concerns
Opportunities	**O1:** Significant breakthroughs in research and development particularly in developing country like Pakistan **O2:** It will create opportunities for investors to come forward for industrial development **O3:** National level waste management policies will improve **O4:** Local level WCO based biodiesel production will rationalize oil and high-speed diesel (HSD) import bills **O5:** Mass scale biodiesel production using large quantity of WCO will improve biodiesel export scenario, external trade and profitability **O6:** Emissions control targets will achieve **O7:** Resource conservation **O8:** It will help out to get rid of illegal waste oil recycling **O9:** Farm diversification options **O10:** Scientific and technical knowledge creation **O11:** Strengthening of economy by clustering agriculture, chemical and energy sector, multidisciplinary areas and diversity in the process for options of holistic development **O12:** Developed models of biodiesel plants could be adopted **O13:** Subsidies and policies could turn this technology economically more feasible **O14:** Challenging national and global policies goals, international focus on sustainable utilization of	**Threats**	**T1:** Investors dwindling response**T2:** Technological process immaturity with high uncertainty**T3:** High capital and operational expenses for pilot scale plants and complete commercial operations**T4:** Global sump in oil prices may push more usage of diesel and gasoline than biofuels**T5:** Market and social acceptance still unclear**T6:** Changing governmental policies**T7:** Goals of end users often focused on single product**T8:** Clear subsidy and taxation policies are still lacking in the short and long term**T9:** No sustainable procurement mechanism available in market**T10:** Lack of blending facilities throughout Pakistan

(*continued on next page*)

Table 1 (*continued*)

Success factors	Failure factors
biomass for bioenergy **O15**: In Pakistan, labor is cheap which can potentially reduce the operational cost of biodiesel production **O16:** To avail opportunity from financing channels to allocate resources from developed countries to under developed countries in this sector [29] **O17:** Continually increasing crude oil prices **O18:** Having carbon credit value (Kyoto protocol) **O19:** Job creation	

effect. In case of biodiesel production from WCO in Pakistan, these three parameters are strongly considered into account. Based on the success factors of WCO based biodiesel production and utilization in Pakistan, its production is a potential and suitable option for the country keeping in view the strength factors including availability of feedstock, the current energy crisis, conventional fuel imports bills, industrial development, investments in renewable energy sector as well as environmental constraints. In addition, for the developing country like Pakistan, it is crucial to take benefits of existing opportunities in this sector for the economic and sustainable growth. Some dogmas for technological development in Pakistan are required to be addressed. The financing mechanisms have been formed to allocate resources from developed countries to unindustrialized nations. This suggests a path for developed countries to stick to their own emission reduction aims under the Kyoto Protocol. The Clean Development Mechanism (CDM) and the Joint Implementation (JI) plan, and the program for Reducing Emissions from Deforestation and Forest Degradation (REDD) are the models of these efforts [33]. The analysis outcomes indicate that there is a strong possibility to overcome failure factors by strength and opportunities existing in country for sustainable biodiesel production and utilization. The need is to update the government policies for providing suitable platform for local and foreign investors, subsidies, social acceptance and adopting financing mechanisms for developing countries.

3.2. AHP analysis

The limitation associated with SWOT analysis is the lack of quantitative values for the factors generated in strategic decision-making and therefore, this technique has been panned for being disorganized and missing projecting power. If SWOT analysis is employed in chorus with an Analytical Hierarchy Process (AHP) which is a multi-criteria decision making tool, the impact of a single factor on the overall decision can be ascertained. In this regard, the clusters of interlinked attributes in previously performed SWOT factors have been made for the effective application of AHP analysis (Table 2).

Table 2 Summarized and critical SWOT factors.

Cluster of Strengths	Cluster of Weaknesses
S1* Waste oil-based feedstock availability and reliability for fuel and energy production (S1, S2, S9, S10, S11, S12, S13, S14)	**W1*** Waste cooking oil purity and recovery issues (W1, W2, W3)
S2 *Government support for RES (S8)	**W2** *Lower energy content than diesel(W4)
S3 *Strengthen economy (S5, S6, S7, S15)	**W3** *Engine performance concerns (W7)
S4 *Environmental protection (S3, S4)	**W4***Road map and commercialization problems (W5, W6)
Cluster of Opportunities	**Cluster of Threats**
O1* Industrial development and profitability (O2, O4, O5, O9, O11, O12, O15, O19)	**T1***Global sump in oil prices (T1, T4, T5, T7)
O2* Breakthrough in R and D (O1, O10)	**T2** *Lacking of blending facilities (T10)
O3* Achievement of emissions control targets and waste management (O3, O6, O7, O8)	**T3***Changing governmental policies (T6, T8, T9)
O4* Availing opportunities of international financing channels (O16, O18)	
O5 *Policies reforms (O3, O13, O14)	

Table 3 presents the priority scores of all factors related to the development of waste cooking oil based biodiesel in Pakistan. All CR values are less than 10%. The priority of each factor within the SWOT group has been provided in the table displaying the experts' opinion in quantitative format. After analysis it appears that the S1* (Waste oil-based feedstock availability and reliability for fuel and energy production) is the most important strength factor with priority value of 0.495 within the group followed by S2*(Government support for RES) with priority value of 0.20. This indicates that waste cooking oil accessibility for fuel production is the most significant strength for the implementation of biodiesel production along with the government support at the second priority. In the category of opportunities, the most important opportunity with the highest priority is O4* (Availing options of international financing channels) followed by O5 * (Policies reforms) placed at the second level with the priority value of 0.17. This presents that there exists a strong opportunity of availing option of financing channels for the development of

Table 3 SWOT–AHP priority scores of waste cooking oil-based biodiesel.

SWOT group	Group priority	SWOT factors	Consistency ratio (%)	Priority of the factor within group	Overall priority of the factor
Strengths	0.51	S1* Waste based feedstock availability and reliability for fuel and energy production	2.2	**0.495**	0.25
		S2* Government support for RES		0.20	0.10
		S3* Strengthen economy		0.14	0.07
		S4 *Environmental protection		0.165	0.08
Weaknesses	0.14	W1* Waste cooking oil purity and recovery issues	8	**0.61**	0.08
		W2 *Lower energy content than diesel		0.05	0.01
		W3 *Engine performance concerns		0.13	0.02
		W4*Road map and commercialization problems		0.21	0.03
Opportunities	0.29	O1* Industrial development and profitability	7.9	0.16	0.05
		O2* Breakthrough in R and D		0.04	0.01
		O3* Achievement of emissions control targets and waste management		0.04	0.01
		O4* Availing opportunities of international financing channels		**0.59**	0.17
		O5 *Policies reforms		0.17	0.05
Threats	0.06	T1*Global sump in oil prices	8.9	**0.63**	0.04
		T2 *Lacking of blending facilities		0.10	0.01
		T3*Changing governmental policies		0.28	0.02

Note:
The CR of the comparisons between four SWOT groups was 7.3%.
The overall factor priority is calculated by taking product of the priority of the factor within the group with the group priority

waste oil-based biodiesel production in the developing country like Pakistan. On the other side, in the category of weaknesses and threats factors, W1* (Waste cooking oil purity and recovery issues) and T1*(Global sump in oil prices) are the major weaknesses and threats which could possibly be faced during biodiesel production scenario.

In addition, the second column of table 3 indicates the group priority of four SWOT factors. It can be deduced from the results that strengths and opportunities displayed the highest values of group priorities with the values of 0.51 and 0.29 respectively. The negative factors such as weaknesses and threats, their group priority values are comparatively lower indicating the positive scenario for the development and implementation of waste oil-based biodiesel production in Pakistan.

Fig. 9. represents the graphical representation of the outcomes of pairwise comparisons of SWOT groups and factors. The comparatively long lines in strengths and opportunities section of the graph represent the dominance of these attributes in comparison with weaknesses and threats. Therefore, AHP analysis of SWOT factors assures the favorable circumstances with respect to strengths and opportunities for the appropriateness of waste oil-based biodiesel production and utilization in Pakistan.

3.3. TOWS analysis

As identified earlier by SWOT analysis the internal strengths & weaknesses and external opportunities & threat, strategies are made to control strengths and overcome weaknesses while exploiting opportunities and avoiding threats. It's necessary to understand that a TOWS analysis will not highlight the definite strategy to adopt rather it displays the zones where action is required, and provide some suggestion of the nature of that action. Detailed TOWS matrix is provided in Table 4. TOWS analysis demands strict requirements to adopt some proposed strategies and recommendations for the effective and sustainable production and utilization of waste cooking oil-based biodiesel in Pakistan. Depending upon the strengths and opportunities with respect to local scenario, weaknesses and threats can possibly be avoided after adopting and implementing the proposed strategies. The strategies and their basis are mentioned in Table 4

3.4. PESTLE analysis

The detailed PESTLE analysis to justify the suitability of WCO based biodiesel production and consumption in Pakistan has been provided.

3.4.1. Political and legal

Alternative Energy Development Board (AEDB) deals with political and legal aspects of biofuel industry in Pakistan. It is the only organization on behalf of the Federal Government that was introduced in May 2003. The core purpose of AEDB is to encourage, assist and promote advancement of renewable energy in Pakistan and with a quest to establish AREs at the faster pace. The regulatory management of AEDB was shifted to Ministry of Water and Power in 2006. The Government of Pakistan (GOP) has authorized AEDB to:-

- Execute programs, strategies and projects in ARE field via private sector
- Provide assistance and facilities for the production and expansion of ARE to accomplish sustainable financial progress

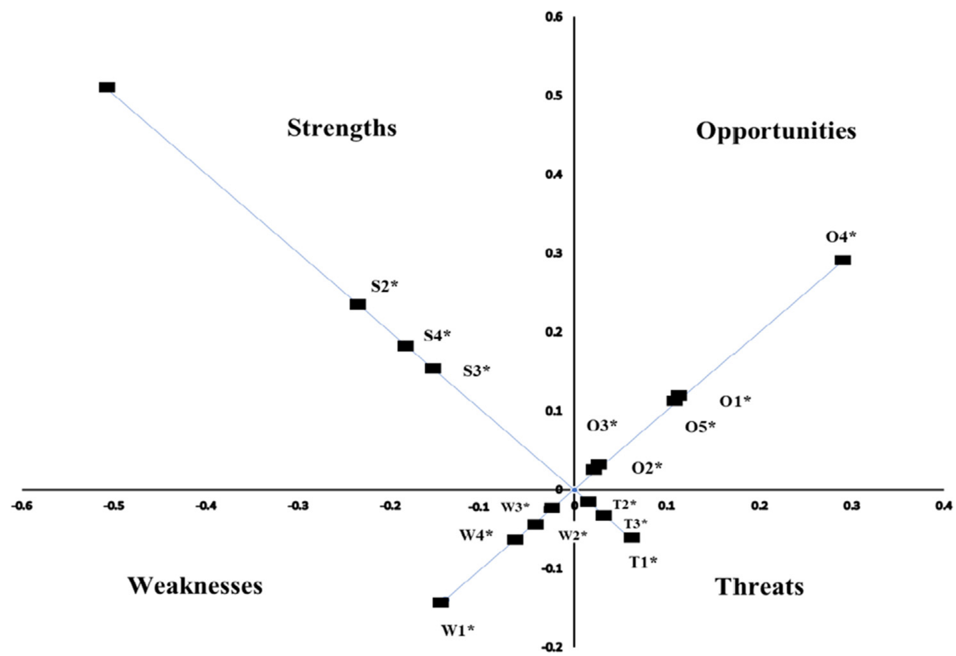

Fig. 9 Graphical representation of the outcomes of pairwise comparisons of SWOT groups and factors.

- Promote technology transfer and expand local industrial foundation for renewable energy technology
- Publicize provision of energy facilities that utilize ARE resources
- Commence ARE projects at commercial level (AEDB Act 2010)

The AEDB was directed by the GOP that 5% of total national power should be produced via AREs systems up to 2030. Furthermore, AEDB has been aimed to electrify approximately 8000 remote villages under the remote village electrification program in Sindh and Balochistan through ARE technologies.

The Federal Government instituted AEDB as a statutory body by declaring and stating the AEDB Act in May 2010. The Act offered AEDB the powers and the duties for the development and marketing of AREs.

Moreover, the Economic Coordination Committee (ECC) of the National Cabinet in 2008 has legalized the plan for the biodiesel utilization as an alternative energy source in its meeting. Important points are as follows:

1. AEDB might be the key planning and supporting organization for the National Biodiesel Program.
2. To achieve a target of 5% (v/v) of biodiesel/diesel blend by 2015 and 10% (v/v) of biodiesel/diesel blend by 2025
3. The Ministry of Petroleum & Natural Resources might devise the fuel quality standards for neat biodiesel and blend up to 20% with mineral diesel
4. Oil Marketing Companies (OMCs) must procure a pure biodiesel and trade it by blending with mineral diesel. [34,35].

Pakistan State Oil (PSO) in cooperation with the Pakistan Agricultural Research Council and the AEDB establish the biodiesel pilot project in 2010. The accomplishment of the pilot plant in 2012 aided to the biodiesel blending by the oil marketing companies from 2013 [36]. Although, statutory bodies of the country are engaged in making policies and setting targets for biodiesel generation and utilization in the upcoming years but the requirement is to facilitate the local and international investors by providing subsidies, tax reductions and multiple incentives.

3.4.2. Technological

The conversion of triglycerides of fatty acids into methyl ester production have been identified for a century. During World War II, the vegetable oils had been proposed for the first time as transport fuels in diesel engines, but feedstock deficiency and the growth of the fossil fuel market discontinued this activity at the premature phase. Then again study on biodiesel generation technology and its utilization in diesel engines originated globally after the oil crisis of 1973. This activity again captured the interest of stake holders and investors from agriculture and industry in Austria and France. In the late 80ies, pilot scale projects were carried out in both countries. Afterward the publication of the world́s first standard for rape oil methyl ester ÖNORM C 1190 provided the ground for the endorsement of FAME as a transportation fuel and for a number of international standards. The quality criteria were published first by ministerial order in France.

The technological aspect discloses the technological improvements and advancements in the industry [37]. There exists a number of captivating techniques for biodiesel production along with a variety of approaches to produce more efficiently and cost-effectively.

In the next section, industrially focused biodiesel technologies are elaborated.

In order to classify the various biodiesel technologies, different possibilities exist. These can be classified; on the basis reaction conditions, catalyst used and operation. Alongside it

Table 4 Detailed TOWS matrix.

	Internal Strengths (S)	**Internal Weaknesses (W)**
	S1: Food security, **S2:** Energy security **S3:** Renewability, **S4:** Waste oil disposal management **S5:** Strengthen rural economies, **S6:** Co-product sales benefits **S7:** Local production reduces diesel import, **S8:** Involvement of country's regulatory authorities, **S9:** Easy adjustment in existing fuel network **S10:** Biodiesel and diesel blend workable **S11:** Utilization in power generation sector, **S12:** No food vs fuel controversy, **S13:** Continuous technology improvement, **S14:** Feedstock reliability **S15:** Glycerol import can be avoided	**W1:** WCO quality issues, **W2:** WCO recovery issues, **W3:** Feedstock quality influence over biodiesel quality, **W4**: Low energy content of biodiesel, **W5:** Roadmap development issues **W6:** Existing gap between R & D and commercialization **W7**: Engine performance concerns
External Opportunities (O) **O1:** R & D breakthroughs in country **O2:** Opportunities for international and local investors **O3:** Waste management policies improvements as per international standards **O4:** Oil and HSD import bills rationalization O5: Biodiesel export and profitability **O6:** Emission control targets achievement **O7:** Resource conservation **O8:** It will help out to get rid of illegal waste oil recycling **O9:** Farm diversification options **O10:** Scientific and technical knowledge creation **O11:** Economy strengthening by clustering agriculture, chemical and energy sector **O12:** Developed model of biodiesel plants adoption **O13:** Subsidies and policies will turn this technology economically feasible **O14:** International focus on sustainable utilization of biomass for bioenergy **O15:** low operational cost due to cheap labor **O16:** To avail opportunity from financing mechanisms to allocate resources from developed countries to under developed countries in this sector **O17:** Continually increasing crude oil prices **O18:** Having carbon credit value (Kyoto protocol) **O19:** Job creation **External threats (T)** **T1:** Investors dwindling response **T2:** Technological process immaturity with high uncertainty **T3:** High capital and operation expenses for commercialization **T4:** Global sump in oil prices may create issues in biodiesel utilization **T5:** Market and social acceptance still unclear **T6:** Changing government policies **T7:** Goals of end users often focused on single product **T8:** Lack of subsidy and taxation policies **T9:** No sustainable procurement mechanism available in market **T10:** Lack of blending facilities throughout Pakistan	**Leverage strengths to exploit opportunities** • Start investments in the development of WCO based biodiesel production plants in country (S1, S3, S7, S14- O2, O3, O7, O12, O15, O16, O18, O19) • Development of R & D framework in country (S7, S13, S14-O1, O10, O16) • Strengthen the country economy through biodiesel production and utilization systems (S5, S6- O4, O5, O11, O16) • Cope up with energy crisis (S2, S11-O5, O14, O17) • Meeting the international targets and technological development in country (S3, S13-O1, O6, O14, O16, O18) **Leverage strengths to reduce vulnerability to threats** • Providing subsidies and tax relief policies to local and international investors for adopting biofuels in country (S3, S8, S14-T1, T3, T7, T8) • Making easy accessibility of biodiesel to the end customers (S9, S10-T5, T7, T9)	**Overcome weaknesses to pursue opportunities** • Building WCO collection and recycling units with improved waste management policies (W1, W2, W3- O2, O3, O16) • Build policies to link up R & D and industrial sector (W5, W6- O1, O13, O14) • Develop diesel–biodiesel blending units (W7-O16, O19) **Minimize weaknesses and avoid threats** • Encouraging market mechanisms in the biofuel sector (W4, W5-T5, T7, T9) • Encourage public private partnerships (W5-T5, T6, T8)

is also conceivable to categorize based on the feedstock type. The technologies utilize half or fully refined vegetable oils land in the category of single feedstock technologies. These technologies require low content of free fatty acids (FFAs) to avoid soap formation. Generally alkaline catalysts are employed and water washing steps or recycled by esterification using acid catalysts are required to deal with the formation of soap as undesired product during the reaction. A small amount of other feedstock like waste cooking oil or higher acidic palm oil can be mixed to the refined vegetable oils through this technology.

On the other side, the multi-feedstock technologies are suitable for treating feedstock with higher amounts of FFAs. Multi feedstock technologies require pre-esterification of the FFAs, or high pressure and temperature process will directly convert all fatty material into FAME in one step. These methods can process any type of raw material, including waste oils, animal fats, acid oils. The reaction conditions are easily adaptable with the change of feedstock. (See Fig. 10.) Since, Pakistan is an emerging nation with limited R & D facilities lying at initial stages of biodiesel production, therefore multi feedstock technologies can be adopted for WCO based biodiesel production.

3.4.3. Social

The effect of the social facet of the biofuel industry usually associates with social development and social stability. WCO based biodiesel production in developing country like Pakistan will not only help in stabilizing diesel prices and shortage but also promote rural development by reducing mineral diesel dependency. The progress in the area of biofuels carries numerous opportunities for developing countries where the high fraction of population resides in rural areas and subsidies on agriculture. In addition, waste oils management issues will be resolved. Utilizing cooking waste oils as raw material to produce biodiesel will eliminate the food verses fuel controversy. Development of new industry will reinforce the country's economic capability by enhancing the total employment rate and indirectly raise the living standard. It will also be a sustainable solution for energy security. The evolution of biodiesel industry can actually activate the development of upstream and downstream industries and help in stabilizing the country's economy.

3.4.4. Environmental

Biodiesel is considered to be environmental friendly fuel having properties such as non-poisonous, renewable, non-flammable, clear smoke and less harmful fumes without aromatic content and sulfur. Biodiesel combustion releases not as much of greenhouse gas emissions such as CO_2, CO, SO_2, hydrocarbon and particulate matter (PMs) compared to mineral diesel consequently diminishes air toxicity. In addition, the drop of 78% CO_2 emissions on a lifecycle basis and lessens smoke due to free soot. WCO as a raw material to produce biodiesel successfully reduces waste oil tackling issues and illegal recycling. The biodegradable nature of biodiesel along with safe handling means any spill over will be simpler and inexpensive to clear-out. Development of biodiesel production plants will also encourage other industries associated with it to do some alteration to ecofriendly production system. It is believed that the biofuels route, if well evaluated, planned and sequenced, could propose win–win–win opportunities to developing countries in terms of rural development, climate change benefits and proper work and energy diversification while leading to a less carbon-intensive economy.

3.4.5. Economic

Development of biodiesel industry in Pakistan will certainly intensify the country's gross income and reduce high speed diesel import bills. It is considered to be a cost effective as its production can be managed locally without any need of importation business. As per our previous research, the overall cost of WCO based biodiesel production in Pakistan is 0.66 $USD{\cdot}L^{-1}$ [17]. The results of cost evaluation obtained for medium-sized plant with 24 $t{\cdot}d^{-1}$ production capacity are presented in Table 5. The details of evaluation can be found in our previous article [17]. Therefore, local manufacturing of WCO based biodiesel in Pakistan is cost effective as compared to mineral diesel whose import is a consistent burden on country's treasure. It will nurture the country's pride as Pakistan's capabilities could be exhibited in the international level. The sustainable biodiesel production will prove to be a vast income source for country by the exportation to other countries.

3.5. Regional recommendations

In order to boost up the implementation of clean technologies, number of models has been utilized in the world at national or local level. Some of these models are not so far cost viable with reference to conventional fuel technologies with high upfront capital costs and therefore provide less incentives for the local investment [38,39]. Whereas some models minimize the high initial investment cost connected with applying renewable

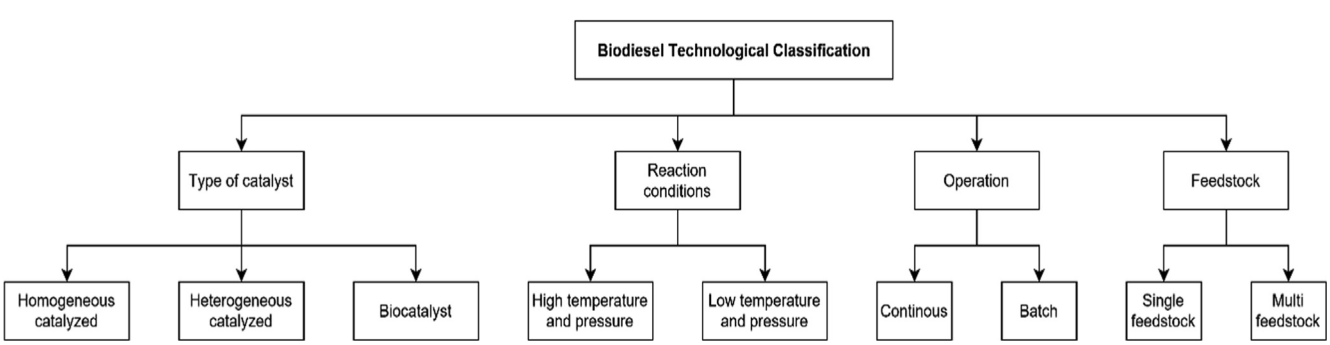

Fig. 10 Biodiesel technological classification.

Table 5 Total operating costs for a 24 tons/day waste cooking oil based biodiesel plant [17].

Factor	Consumption/day	Cost(USD/ unit)
Raw Materials and utility		
WCO	24648 kg	0.47/kg
Water	3.36 m^3	0.031/kg
Alcohol (methanol)	5184 kg	0.48/kg
Acid catalyst (H_2SO_4)	1952 L	0.23/kg
CaO used	2160 kg	0.1/kg
Electricity	3960 kW h	0.2 kW h
Additional operating costs		
Labor	9 Person/d (in 3 shift)	1.6/person/h
Supervision and general administrative costs	3 Person/day	2/person/h
Maintenance supplies		76/day
Total Operating cost	**18,436 USD**	**0.66 /L biodiesel**

Note:
● November 2018 Pakistan market data was considered for price estimation.
● 98% reaction conversion was assumed.
● The profit associated with by-product sales was not considered.
● Pakistan's ministry of labor laws were considered for basal labor wages and other expenses.

energy projects and others upsurge the profits from the sales of green energy. First one would be called "supply incentives" and second class "demand incentives". The grants, tax relief options or subsidies come in the category of Supply incentives that provide aid in setting up renewable energy technologies, on the other side, demand incentive guarantee the premium imbursement for the energy that obtains from clean sources of energy. Feed-in Tariff (FIT) is the most commonly used form of the latter which ensures an energy cost directly related to its production expense.[40] Alternative thought-provoking model adopted in industrialized as well as developing nations with the support of World Bank is Energy Service Companies or ESCOs. Energy users of a particular location are contracted by these companies to recognize energy saving ventures and are later repaid from the energy savings that generate from the investments. China, Brazil, Vietnam, Uruguay, India, Turkey and Thailand, are the countries which have adopted this model [38].

Another major problem in most countries is the situation of out of place subsidies in which government provides subsidies on conventional fossil fuels instead of promoting renewable sector to lessen the financial load of global prices. These subsidies obstruct the development of renewable technologies. It would be more favorable to rationalize subsidies to renewable energy sources for a quick aquisition of renewable technologies rather continuing the utilization of fossil fuels.

It is important that renewable technologies such as biodiesel plant set ups may be installed in rural areas with no trouble. In a developing country like Pakistan, wheremore than 70% of inhabitants reside in rural areas and hence assures the reliability of feedstock for biodiesel production. In these sites, the deficiency of basic framework for traditional energy sources may make it more profitable to put in local renewable energy systems [41]

Moreover, in order to fulfill energy demands in developing economies, application and utilization of new technologies itself has prospective to uplift the country's economic development. This will lead to the development of new industries along with new job creations while encouragingD domestic remodellingand technological progress [42]

4. Conclusion

At present, Pakistan stands among those countries where biodiesel as a renewable fuel is either least or less focused. Although there exists potential suitability of WCO based biodiesel production and utilization which is analyzed through SWOT-AHP, TOWS and PESTLE analysis to some extent. There are policies and targets set by the governing bodies of the country for conventional fuel transformation but still country lacks appropriate policies, implementation procedures and government support to capture the attention of local and international investors in this area. The tentative quantification of strengths and opportunities in SWOT-AHP and TOWS matrix are in good favor of WCO based biodiesel production and consumption in country. Considering strengths and taking benefits from opportunities can easily suppress weaknesses and threats. In addition, there seems no apparent hindrance in this sector instead initiating biodiesel production projects would help in stabilizing country's economy along with ensuing the international trend toward biofuels.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. 1 Compiled version of experts' perception, decision matrix and factor priorities for **Strengths**

With respect to *AHP priorities*, which criterion is more important, and how much more on a scale 1 to 9?

	A - wrt AHP priorities - or B?		Equal	How much more?
1	● Feedstock availability and reliability	○ Government support for RES	○ 1	○2 ●3 ○4 ○5 ○6 ○7 ○8 ○9
2	● Feedstock availability and reliability	○ Strengthen economy	○ 1	○2 ●3 ○4 ○5 ○6 ○7 ○8 ○9
3	● Feedstock availability and reliability	○ Environmental protection	○ 1	○2 ●3 ○4 ○5 ○6 ○7 ○8 ○9
4	● Government support for RES	○ Strengthen economy	○ 1	●2 ○3 ○4 ○5 ○6 ○7 ○8 ○9
5	● Government support for RES	○ Environmental protection	● 1	○2 ○3 ○4 ○5 ○6 ○7 ○8 ○9
6	● Strengthen economy	○ Environmental protection	● 1	○2 ○3 ○4 ○5 ○6 ○7 ○8 ○9

CR = 2.2% OK

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AHP Scale: 1- Equal Importance, 3- Moderate importance, 5- Strong importance, 7- Very strong importance, 9- Extreme importance (2,4,6,8 values in-between).

Priorities

These are the resulting weights for the criteria based on your pairwise comparisons:

Cat		Priority	Rank	(+)	(-)
1	Feedstock availability and reliability	49.5%	1	7.2%	7.2%
2	Government support for RES	20.0%	2	5.4%	5.4%
3	Strengthen economy	14.0%	4	3.0%	3.0%
4	Environmental protection	16.5%	3	2.4%	2.4%

Number of comparisons = 6
Consistency Ratio CR = 2.2%

Decision Matrix

The resulting weights are based on the principal eigenvector of the decision matrix:

	1	2	3	4
1	1	3.00	3.00	3.00
2	0.33	1	2.00	1.00
3	0.33	0.50	1	1.00
4	0.33	1.00	1.00	1

Principal eigen value = 4.061
Eigenvector solution: 4 iterations, delta = 2.1E-9

2 Compiled version of experts' perception, decision matrix and factor priorities for **Opportunities**

With respect to *AHP priorities*, which criterion is more important, and how much more on a scale 1 to 9?

	A - wrt AHP priorities - or B?		Equal	How much more?
1	◉ Industrial development and profitability	○ Breakthrough in R and D	○ 1	○2 ○3 ○4 ◉5 ○6 ○7 ○8 ○9
2	◉ Industrial development and profitability	○ Achievement of emission control & waste manag	○ 1	○2 ○3 ○4 ◉5 ○6 ○7 ○8 ○9
3	○ Industrial development and profitability	◉ Availing opportunities of financing channels	○ 1	○2 ○3 ○4 ○5 ○6 ◉7 ○8 ○9
4	◉ Industrial development and profitability	○ Policies reforms	◉ 1	○2 ○3 ○4 ○5 ○6 ○7 ○8 ○9
5	◉ Breakthrough in R and D	○ Achievement of emission control & waste manag	◉ 1	○2 ○3 ○4 ○5 ○6 ○7 ○8 ○9
6	○ Breakthrough in R and D	◉ Availing opportunities of financing channels	○ 1	○2 ○3 ○4 ○5 ○6 ◉7 ○8 ○9
7	○ Breakthrough in R and D	◉ Policies reforms	○ 1	○2 ○3 ○4 ◉5 ○6 ○7 ○8 ○9
8	○ Achievement of emission control & waste manag	◉ Availing opportunities of financing channels	○ 1	○2 ○3 ○4 ○5 ○6 ◉7 ○8 ○9
9	○ Achievement of emission control & waste manag	◉ Policies reforms	○ 1	○2 ○3 ○4 ◉5 ○6 ○7 ○8 ○9
10	◉ Availing opportunities of financing channels	○ Policies reforms	○ 1	○2 ○3 ○4 ◉5 ○6 ○7 ○8 ○9

CR = 7.9% OK

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AHP Scale: 1- Equal Importance, 3- Moderate importance, 5- Strong importance, 7- Very strong importance, 9- Extreme importance (2,4,6,8 values in-

Priorities

These are the resulting weights for the criteria based on your pairwise comparisons:

	Cat	Priority	Rank	(+)	(-)
1	Industrial development and profitability	15.9%	3	5.3%	5.3%
2	Breakthrough in R and D	4.4%	4	2.0%	2.0%
3	Achievement of emission control & waste manag	4.4%	4	2.0%	2.0%
4	Availing opportunities of financing channels	58.7%	1	32.2%	32.2%
5	Policies reforms	16.5%	2	4.2%	4.2%

Number of comparisons = 10
Consistency Ratio CR = 7.9%

Decision Matrix

The resulting weights are based on the principal eigenvector of the decision matrix:

	1	2	3	4	5
1	1	5.00	5.00	0.14	1.00
2	0.20	1	1.00	0.14	0.20
3	0.20	1.00	1	0.14	0.20
4	7.00	7.00	7.00	1	5.00
5	1.00	5.00	5.00	0.20	1

Principal eigen value = 5.356
Eigenvector solution: 6 iterations, delta = 3.1E-8

3 Compiled version of experts' perception, decision matrix and factor priorities for **Weaknesses**

With respect to *AHP priorities*, which criterion is more important, and how much more on a scale 1 to 9?

	A - wrt AHP priorities - or B?		Equal	How much more?
1	(●) Waste oil purity and recovery issues	( ) Lower energy content than diesel	( ) 1	9
2	(●) Waste oil purity and recovery issues	( ) Engine performance concerns	( ) 1	5
3	(●) Waste oil purity and recovery issues	( ) Road map and commercialization problems	( ) 1	4
4	( ) Lower energy content than diesel	(●) Engine performance concerns	( ) 1	4
5	( ) Lower energy content than diesel	(●) Road map and commercialization problems	( ) 1	3
6	( ) Engine performance concerns	(●) Road map and commercialization problems	( ) 1	3

CR = 8% OK

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AHP Scale: 1- Equal Importance, 3- Moderate importance, 5- Strong importance, 7- Very strong importance, 9- Extreme importance (2,4,6,8 values in-between).

Priorities

These are the resulting weights for the criteria based on your pairwise comparisons:

	Cat	Priority	Rank	(+)	(-)
1	Waste oil purity and recovery issues	60.8%	1	14.9%	14.9%
2	Lower energy content than diesel	5.3%	4	1.7%	1.7%
3	Engine performance concerns	12.6%	3	5.5%	5.5%
4	Road map and commercialization problems	21.4%	2	9.9%	9.9%

Decision Matrix

The resulting weights are based on the principal eigenvector of the decision matrix:

	1	2	3	4
1	1	9.00	5.00	4.00
2	0.11	1	0.25	0.33
3	0.20	4.00	1	0.33
4	0.25	3.00	3.00	1

Number of comparisons = 6
Consistency Ratio CR = 8.0%

Principal eigen value = 4.219
Eigenvector solution: 5 iterations, delta = 5.8E-8

4 Compiled version of experts' perception, decision matrix and factor priorities for **Threats**

With respect to *AHP priorities*, which criterion is more important, and how much more on a scale 1 to 9?

	A - wrt AHP priorities - or B?		Equal	How much more?
1	◉ Global sump in oil prices	○ Lack of blending facilities	○ 1	○2 ○3 ○4 ◉5 ○6 ○7 ○8 ○9
2	◉ Global sump in oil prices	○ Changing governmental policies	○ 1	○2 ◉3 ○4 ○5 ○6 ○7 ○8 ○9
3	○ Lack of blending facilities	◉ Changing governmental policies	○ 1	○2 ○3 ◉4 ○5 ○6 ○7 ○8 ○9

CR = 8.9% OK

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AHP Scale: 1- Equal Importance, 3- Moderate importance, 5- Strong importance, 7- Very strong importance, 9- Extreme importance (2,4,6,8 values in-between).

Priorities

These are the resulting weights for the criteria based on your pairwise comparisons:

Cat		Priority	Rank	(+)	(-)
1	Global sump in oil prices	62.7%	1	18.1%	18.1%
2	Lack of blending facilities	9.4%	3	2.7%	2.7%
3	Changing governmental policies	28.0%	2	8.1%	8.1%

Number of comparisons = 3
Consistency Ratio CR = 8.9%

Decision Matrix

The resulting weights are based on the principal eigenvector of the decision matrix:

	1	2	3
1	1	5.00	3.00
2	0.20	1	0.25
3	0.33	4.00	1

Principal eigen value = 3.086
Eigenvector solution: 5 iterations, delta = 9.1E-9

5 Compiled version of experts' perception, decision matrix and SWOT **group priority**

With respect to *AHP priorities*, which criterion is more important, and how much more on a scale 1 to 9?

	A - wrt AHP priorities - or B?		Equal	How much more?
1	◉ Feedstock availability and reliability	○ Waste oil purity and recovery issues	○ 1	○ 2 ◉ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
2	◉ Feedstock availability and reliability	○ Availing options of financing channels	○ 1	○ 2 ◉ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
3	◉ Feedstock availability and reliability	○ Global sump in oil prices	○ 1	○ 2 ○ 3 ○ 4 ◉ 5 ○ 6 ○ 7 ○ 8 ○ 9
4	○ Waste oil purity and recovery issues	◉ Availing options of financing channels	○ 1	○ 2 ◉ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
5	◉ Waste oil purity and recovery issues	○ Global sump in oil prices	○ 1	○ 2 ◉ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
6	◉ Availing options of financing channels	○ Global sump in oil prices	○ 1	○ 2 ○ 3 ○ 4 ◉ 5 ○ 6 ○ 7 ○ 8 ○ 9

CR = 7.3% OK

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AHP Scale: 1- Equal Importance, 3- Moderate importance, 5- Strong importance, 7- Very strong importance, 9- Extreme importance (2,4,6,8 values in-

Priorities

These are the resulting weights for the criteria based on your pairwise comparisons:

Cat		Priority	Rank	(+)	(-)
1	Feedstock availability and reliability	50.5%	1	22.3%	22.3%
2	Waste oil purity and recovery issues	14.3%	3	4.0%	4.0%
3	Availing options of financing channels	28.8%	2	10.2%	10.2%
4	Global sump in oil prices	6.4%	4	2.2%	2.2%

Number of comparisons = 6

Consistency Ratio CR = 7.3%

Decision Matrix

The resulting weights are based on the principal eigenvector of the decision matrix:

	1	2	3	4
1	1	3.00	3.00	5.00
2	0.33	1	0.33	3.00
3	0.33	3.00	1	5.00
4	0.20	0.33	0.20	1

Principal eigen value = 4.198

Eigenvector solution: 6 iterations, delta = 1.2E-9

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