DOI 10.3390/su141811388
ISSN 2071-1050

Publisher: MDPI

sustainability

MDPI

Article

Assessment of Sustainable Biomass Energy Technologies in Pakistan Using the Analytical Hierarchy Process

Hira Soomro [1], Syed Feroz Shah [1], Wasayo Sanam Sahito [2], Mohammad Aslam Uqaili [3], Laveet Kumar [4,*], Jonathan Daniel Nixon [5] and Khanji Harijan [4,*]

[1] Department of Basic Sciences and Related Studies, Mehran University of Engineering & Technology, Jamshoro 76062, Pakistan
[2] Civil Engineering Department, College of Engineering and Islamic Architecture, Umm Al-Qura University, Makah 24381, Saudi Arabia
[3] Department of Electrical Engineering, Mehran University of Engineering & Technology, Jamshoro 76062, Pakistan
[4] Department of Mechanical Engineering, Mehran University of Engineering & Technology, Jamshoro 76062, Pakistan
[5] Faculty of Engineering, Environment and Computing, Coventry University, 1 Gulson Road, Coventry CV1 2JH, UK
* Correspondence: laveet.kumar@faculty.muet.edu.pk (L.K.); khanji.harijan@faculty.muet.edu.pk (K.H.); Tel.: +92-3332786913 (L.K.)

Highlights:

What are the main findings?

- Assessment of three cookstove technologies using the AHP.
- Technological, social, economic, and environmental criteria were evaluated.

What is the implication of the main finding?

- The technologies were assessed using four main criteria corresponding to 12 sub-criteria.
- ECS technology is the most advantageous technology, followed by BCS and TCS.

Abstract: Pakistan is not merely confronting the energy crisis but also dealing with the scarcity of economical technologies for the utilization of energy resources. From the basic resources, renewable energy is one of the considerable resources. Due to environmental issues related to greenhouse gases (GHGs) and air pollution in Pakistan, the other energy resources are constricted. In rural areas, biomass resources are a fundamental need for domestic purposes. The prominent reason for environmental degradation and deforestation is due to ineffective use of such resources. Biomass resources for heating and cooking purposes are abundantly available in rural areas of Pakistan. In this context, this study helps us select the applicable cookstove technologies for the Sindh province for the proper utilization of biomass resources. The AHP (analytical hierarchy process) was used as the central methodology for the cookstove ranking. Concerning its improvement, four main criteria corresponding to 12 sub-criteria were considered for the selection of three cookstove technologies, i.e., traditional cookstoves (TCS), efficient cookstoves (ECS), and biogas cookstoves (BCS). The final decision of the AHP framework exposed the ECS technology as the advantageous technology, followed by the BCS and TCS, respectively. To analyze the results, a sensitivity analysis of the major results has also been carried out, and under the final ranking matrix, the ECS alternative got the highest weightage, nearly 36.56%, based on the developed model.

Keywords: biomass energy; analytical hierarchy process; cookstoves; sensitivity analysis; Pakistan

Citation: Soomro, H.; Shah, S.F.; Sahito, W.S.; Uqaili, M.A.; Kumar, L.; Nixon, J.D.; Harijan, K. Assessment of Sustainable Biomass Energy Technologies in Pakistan Using the Analytical Hierarchy Process. *Sustainability* **2022**, *14*, 11388. https://doi.org/10.3390/su141811388

Academic Editor: Adam Smoliński

Received: 17 August 2022
Accepted: 6 September 2022
Published: 10 September 2022

1. Introduction

For the development of any nation in a socio-economical manner, energy performs a vital role [1,2]. Multiple sources of energy, including wind, coal, and nuclear petrol, have been assessed by humans [3]. It is impossible to endure without energy in the modern era. Currently, due to sensitivities of environmental and energy issues in the public and political sector, renewable energy resources get the core attention. Biomass is one of the sources of clean energy that is likely to play a key role. It has been used for decades as just a primary energy source. Being a farming country, Pakistan attains a vigorous economic position [4,5]. The population of Pakistan and its growth rate is around 223 million and 5.71 percent (annually), respectively [6,7]. Due to the continuous increase in population, Pakistan is in the fifth position as one of the world's most heavily populated countries. Even though Pakistan is blessed with immense primarily renewable resources, for harnessing these resources, very negligible effort is noted. Ergo, the national energy system has restricted energy supplies and referred to the country as having an energy deficiency.

Figure 1 shows that around 65% of Pakistan's population occupies pastoral regions, and cultivation is their principal mean of earning. Biomass is the green energy option that has solved a continuous energy problem [8,9]. Renewable energy supplies are the most dispersed sources of energy, and numerous nations have made countless attempts toward its utilization [10,11]. Both rural and urban households with less income usually acquire their daily heat through the combustion of traditional fuel, such as animal dung (fertilizer), bagasse, wood, and agricultural residues. Additionally, the portion of cooking fuel consumed inside rural regions of Pakistan in the year 2011 is given in Figure 2 [3].

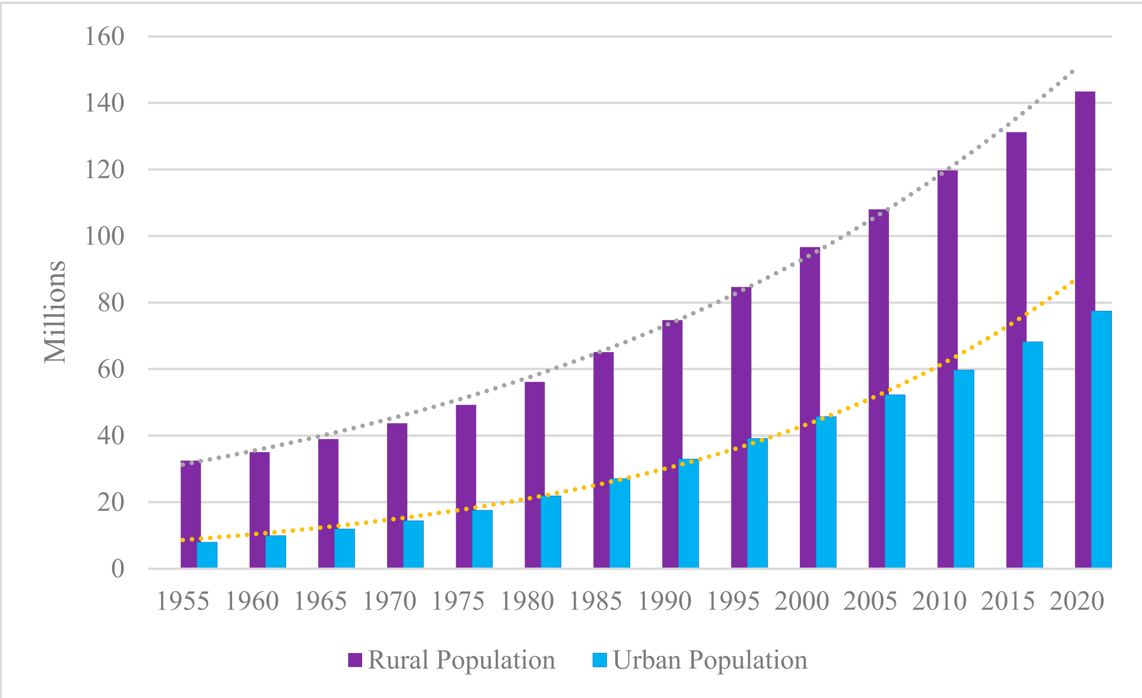

Figure 1. Rural vs. urban population [6].

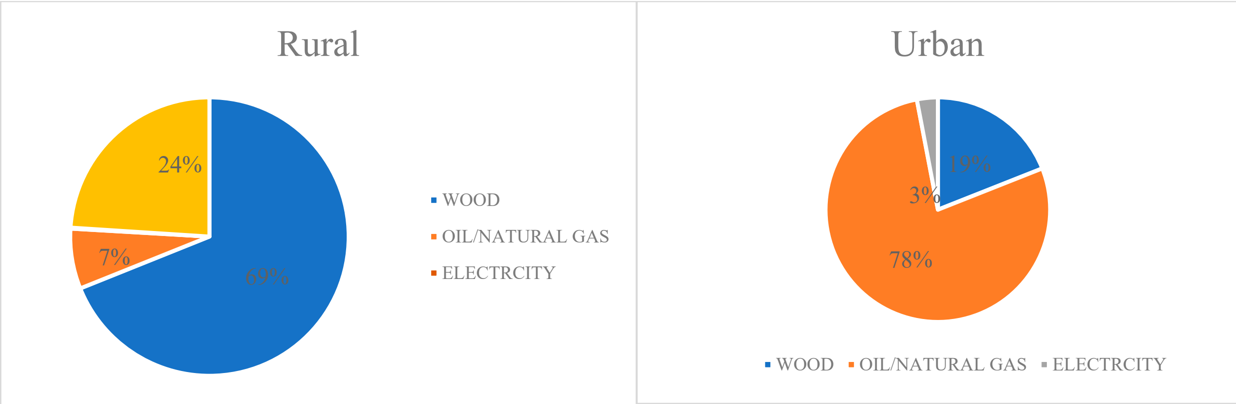

Figure 2. Cooking fuel consumption in rural and urban regions.

In Pakistan, mostly solid fuel is consumed for cooking, among which the urban households have 13% of the value, whereas 87% of the consumption is made by rural households [12]. Solid fuels emit chemicals and pollutants, while their open combustion is hazardous for health [12,13].

Energy impersonates an integral part in social and economic advancement through improving the norms of human beings. The population of Pakistan is unable to control the limited resources. Globally, these shortages can be overcome by the utilization of renewable energies in Pakistan [14]. Green resources development not only solves the energy crisis, but it also saves enormous import bills [15].

In Pakistan, considering different sectors of the economy, energy demand is increasing constantly. In rural areas, Biomass is a feasible resource of energy for cooking purposes. It is difficult to make an acceptable decision while considering the characteristics of biomass energy for cooking stoves. The present research aims to establish an AHP model for the selection of alternative cookers for rural regions. The current study has encompassed the initial research efforts. Initially, it has described the consumption of biomass in Pakistan. Moreover, the biomass-based cookstoves are also reviewed in the current part based on models, performance, complications, and diffusion; brief literature on ECS, TCS, and BCS is also presented. Finally, the modus operandi of AHP in MCDM for a selection of an alternative is also examined.

2. Utilization of Biomass in Rural Areas

In the world, biomass is considered a mega source for power production. It almost accounts for thirty-three percent (33%) of the country's energy consumption, touching the range from 75% to 90% in countries like Paraguay, Kenya, and Bangladesh. Moreover, the rural areas have a higher ratio of 56% due to the paramount usage of fuelwood for cooking and heating. Additionally, there is a divergence between rural and urban energy systems, as depicted by the practice and the quantitative outgo of energy. Likewise, the urban systems depend upon commercial sources, and the rural system is entirely reliant on non-commercial-based energy sources like cow manure, fuelwood, and likewise [16,17]. Almost 62% of Pakistan's population belongs to rural areas, accomplishing their domestic necessities of heating and cooking through the ineffectual and inefficient burning of biomass (TCS) that does not only cause indoor air pollution (IAP) but also promotes deforestation. An evaluation of ECS/ICS has been made on their capacity for the conservation of biomass inside Pakistan and found that more than the 50% of the biomass utilization in both functions of cooking and heating mayhap will be conserved via replacing TCS with ECS, as depicted by the Figure 3 [18,19].

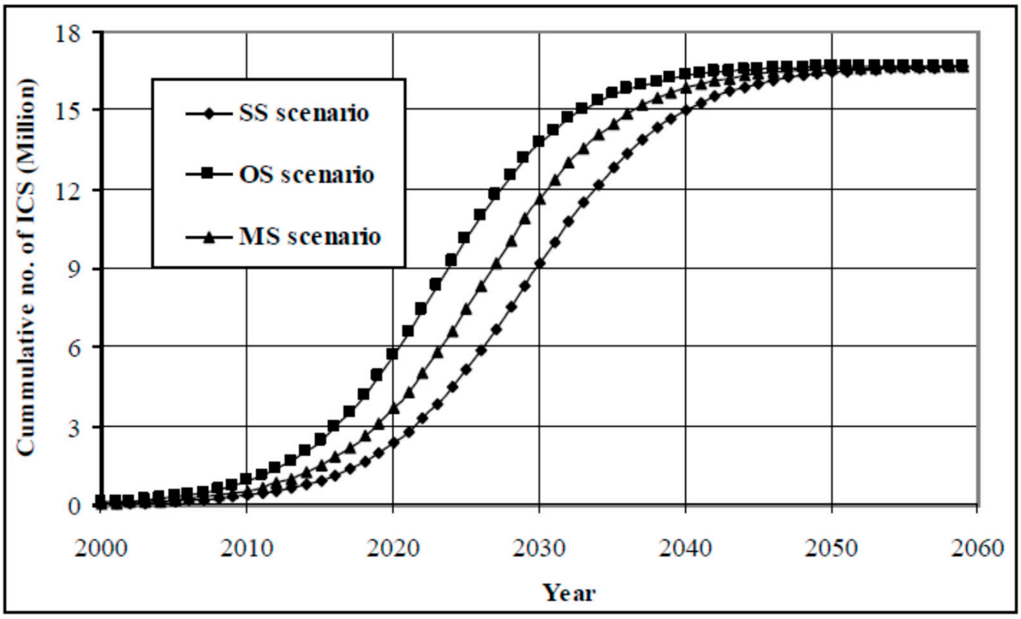

Figure 3. The total estimated number of ECS installations in Pakistan [18].

3. Technologies for Biomass Resources

Rural areas usually are affected by a specific form of heat by smoldering in inherited (three rock fire-cook) cookers. Combustion of biomass produces substantial exposure to indoor air pollution (IAP) to infants and females during daily cooking hours. Additionally, this IAP will further increase the risk of severe respiratory diseases amongst children, and chronic obstructive pulmonic infections in adults are the most common causes of death under these age groups in developing countries [11,20–22]. Classifications of cooking stoves have been classified into three categories, which are briefly elaborated on below.

3.1. Traditional Cook Stoves (TCS)

The normally used cooking stoves are named traditional cooking stoves. These are constructed by placing three stones in a triangle or U-shaped design. The reasonably priced stove is TCS, which can be found in various nations in the world. The heat amount transferred is quite low. Due to the smoke, health is also affected. About 20% is its maximum efficiency, and it is dangerous, possessing excessive radiations of carbon monoxide and particulate matter (PMs) [15].

3.2. Efficient Cook Stoves (ECS)

ECSs are made to minimize effusions with enhanced performance. An ICS enhancement uses the low price to devastate TCS faults. Experimentally, ICS reduces hazardous emissions by 40–75%, while increasing gas efficiency by 30% [23]. A chimney is attached that provides a healthy combustion feature by eliminating internal air pollution and raises its value. The ECS covers a furnace in which the demand for the gas to be burned, the presence of air, and the excess heat generated are provided only for cookery.

3.3. Biogas Cook Stoves (BCS)

Domestically, waste-originated biogas could also be utilized as a fuel. Essentially, it is an amalgam of CO_2 (35%) and CH_4 (65%). Stove design is established specifically for the low-pressure gas flames. Biogas burns out over a small variety of mixtures comprising of 9–17 percent of the air-surrounded biogas, for example. If there is a tremendous amount of gas in the burning fire, there will be deficient burning, providing toxic CO gas and smoke particles [24]. Its design has extensive health advantages compared to the TCS, which is an open-fire stove. Smokeless cooking is carried out that reduces the health-related issues of breathing and eye infections. Anaerobic digestion can alleviate sewage sludge and convert the carbon-based compounds into methane. Additionally, anaerobic digestion converts animal waste into fertilizer [25,26].

4. MCDM for Selection of Biomass Energy Technologies

Distinct surveys have been carried out for the assessment of the energy capability of biomass resources in Pakistan. However, when it comes to using the MCDM method for the selection of energy technologies for biomass, no research has been conducted in Sindh. MCDM with its branches is briefly described in the subsequent section.

4.1. Multi-Criteria Decision Making (MCDM)

Multi-criteria decision-making, a general class of organizational analysis models, is the esteemed decision-making division that deals with decision-making problems amid a variety of selection processes. MCDM considers both qualitative and quantitative parameters. The multi-criteria methodology is a versatile instrument that has the potential to manage a variety of variables measured in changed behaviors and hence indicate the decision-valuable maker's assistance in mapping the problem. There are two large MCDM domains, as seen in Figure 4: multi-objective decision-making (MODM) and, multi-attribute decision-making (MADM).

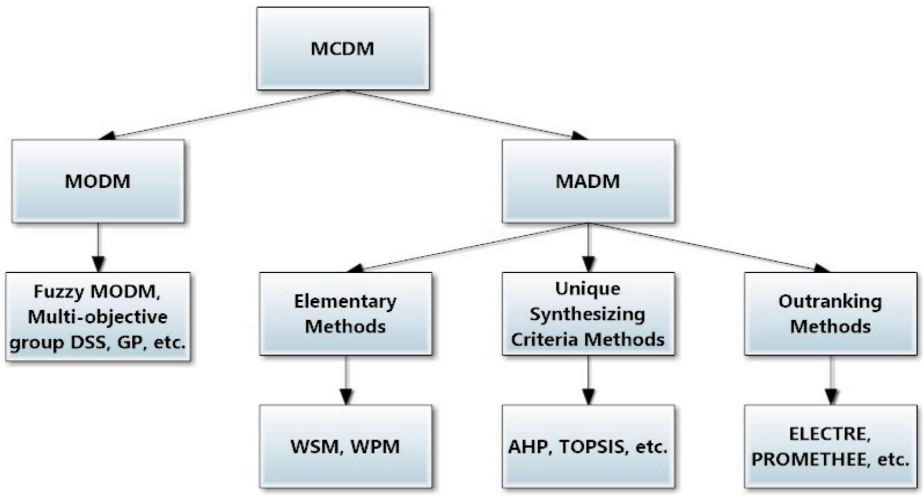

Figure 4. MCDM methodology hierarchy [27].

One of the MADM methods is the AHP, and it is a growing application in the energy system dilemma decision process [28–31]. A detailed overview of the AHP modus-operandi is given in the following section.

4.1.1. AHP for Selection of Biomass Energy Technologies

In sustainable energy management, the analytic hierarchy process (AHP) modus operandi has gained popularity. This methodology helps in solving problems that include numerous conflicts and objectives. I.-S. Antonopoulos et al. in 2014 showed that the analytical hierarchy process is also applied to compare and evaluate municipal solid-waste management. Moreover, this study encompasses the performance of sensitive analysis [29]. The analytic hierarchy process has also been utilized in an agglomeration of green energy models, according to the Spanish government [28]. Further, the study by Salman Ahmad et al. in 2013 had also applied the same procedure in Malaysia for electricity generation while using AHP for energy sources. Moreover, the same procedure helps administrators to articulate a long-term renewable energy agenda for sustainability [32]. Efforts were made by Sunil Luthra et al. in 2014 in India to pick up on and prioritize the bottlenecks in the endorsement of 'green and renewable' energy technologies while applying the technique of the analytic hierarchy process [33]. JingzhengRen et al. in 2015 also used AHP for opting for the most reliable sources of energy for China. He included low-carbon energy sources like wind, biomass, hydro, nuclear, and solar. The analytic hierarchy process, owing to its multi-perspective analysis in its usage, is highly appreciated in the energy sector [34]. On another side in Nepal, Prajapati and Nakarmi [8] depicted that presently, an influential synopsis is very much crucial in the country. After reviewing relevant literature, the appropriate selection of the model transformed into a formulated one that included criteria, sub-criteria, goals, and alternatives. Finally, the AHP model was originated to highlight the attraction of technologies in the imperative end-user assistance of a household territory.

The analytic hierarchy process and skillfully preferred models are unlike financial and managemental models, in which they should include all factors, quantitative and qualitative or objective and subjective. Including ample iteration, the outcome of an expert option would still make sense. In a few cases, the iteration will change the expectations of alternatives to fit one's instincts, whereas in most situations, the impulse shifts due to the insight gained from the model. The AHP reduces a complex problem to a classification that serves an upper purpose, a level of quality, a level of sub-standard, and decision-making alternatives, as shown in Figure 4 below. As a result, at the highest level, each element is connected in pairs to define its preference. To estimate the strength of the preference between the two elements, Saaty's Likert scale of 1–5 is used [28]. Furthermore, the factors that influence the development of the model and its effects are discussed below.

4.1.2. Factors Affecting the Selection of Biomass Energy Technologies

A literature review of multiple factors that influence the model's development has been examined. Moreover, Table 1 presents various cooking stoves and their related technical and financial parameters. Accordingly, it revealed that the design of the biogas cookstove has a higher status. Even so, because of its affordability, the TCS is more favored than the BCS and the ECS. In addition, the literature also shows that the TCS contains more CH_4, CO_2, NO_2, and particulate matter after BCS and ECS.

Table 1. Factors affecting selection of technologies.

Main Criteria	Sub-Criteria		Alternatives			References
			(TCS)	(ECS)	(BCS)	
Technological	Design		Poor	Good	Better	[35–37]
	Reliability		Medium	Low	High	[20,38]
	Efficiency		9–13%	20–40%	45–55%	[7,39]
	Availability		High	Medium	Low	[35,36,38]
Environmental	Particulate Matter $\mu g/m^3$		717.1	186.3	210.2	[40,41]
	Emissions ($kg\ TJ^{-1}$)	CO_2	-	-	-	[20,35,36,41]
		CH_4	519.6	408	57.8	
		N_2O	3.74	4.83	5.2	
Social	Community Acceptance		Commonly used, requires more amount of wood	Better, faster, and requires less amount of wood consumption	Clean sources, reduces indoor pollution, gender equality, saves time, not easily affordable	[8,39]
	Ease concerning Usage		Easiness in utilization	reduced smoke emissions	well-built and enduring	[19,38]
	Effect on standard of living		room air polluting	low wood utilization	purifying, prevents landfilling	[34,41]

Table 1. *Cont.*

Main Criteria	Sub-Criteria	Alternatives			References
		(TCS)	(ECS)	(BCS)	
Economical	Investment Cost (US $)	5.5	27.4	100–300	[23,24]
	operational and maintaining price (US $)	Nil	1.4	biogas stove has zero maintenance price	[13,36,41]
	Affordability	High	Medium	Low	[37,39]

The ECS necessitates a small amount for cookery. Hence, it is considered the best choice for community approval. Moreover, in the comparison of ECS and TCS, BCS is preferred, as it demands a clean source, emits minute, reasonable indoor air pollution, and preserves time. Biogas influences the quality of life. Additionally, the biogas cookstove has a higher initial cost than the TCS and ECS, whereas the TCS is more affordable. As per this study, the AHP model is formed for the choice of cookers in Sindh, where four fundamental standards, including twelve sub-standards, were recognized for the analyzing of biomass energy technologies.

5. Methodology

The selection of appropriate cookstove technologies, based on biomass resources for the Sindh province by applying the AHP technique of MCDM, was considered in this study. The weights and ranking for the appropriate cookstoves were determined with the help of AHP. A detailed AHP description is given below.

5.1. Study Area and Assortment of Data

To collect data from various regions in Sindh, a questionnaire was prepared for an accurate response from locals, especially women. Moreover, ten respondents were authorized to sort out the questionnaire to know locals' viewpoints regarding multiple criteria for choosing suitable alternative technology (BCS, ECS, and TCS). For evaluation, the AHP technique was used to assess the assembled information, and for that, the sample volume required was to be reliable and central. Figure 5 represents the regions selected for the collection of data for the questionnaire.

The examined hamlets are shown in Table 2, located in the Khairpur, Hyderabad, and Tharparkar districts of Sindh, Pakistan. Setharja is a village in Thari Mirwah Tehsil, Khairpur District of Sindh. Its directions are 27.2043° N, 68.4801° E. The figures of homes and inhabitants is given in Table 2. Khaskheli village is situated on the correct bank of the Indus, close to the thruway. The area of this town is 25.456786° N, 68.365135° E. Cultivating is generally around this town. It ought to be noticed that there is likewise a cows' ranch. Mehrand is another town close to Mehrand Lake. It is situated close to Tharparkar town of Kaloi. Its topographical position is 24.685500° N, 69.312764° E. The number of inhabitants in Mehrand town is around 490, as portrayed in Table 2.

Table 2. List of chosen Rural regions of Sindh.

Surveyed Area	Names of Villages	Population	Number of Households
Khairpur	Setharja	1500	220
Hyderabad	Khaskheli Village	720	60
Tharparkar	Mehrand	490	70

Figure 5. The geographic position of distinctive villages in Sindh (Google maps).

Initially, the questionnaire was prepared in English, but due to the native language of respondents, it was changed to Sindhi. Additionally, the educational level of surveyed villages was 76% literate and 24% illiterate.

5.2. Analytical Hierarchy Process (AHP)

The analytical hierarchy process is measurement through assessments and the estimation of importance. This method evaluates pairwise comparisons through which alternatives involving several criteria with their estimated weight can be compared. The usage of pairwise correlations permits chiefs to weigh coefficients and think about other options. To accommodate the decision-making problems, it can easily be adjusted in size because of its hierarchical structure [28,42,43]. Concerning AHP, a complicated problem is a breakdown into a hierarchical order, with objectives at the upper hierarchy level followed by criteria and sub-criteria at levels and sublevels of the hierarchy; decision alternatives are placed at the bottom of the hierarchy, which is presented in Figure 5. To evaluate the strength of preference between two elements, Saaty's Likert 1–5 scale is utilized. On the scale, 1 shows equivalent significance, 2 demonstrates modestly more significance, 3 demonstrates firmly more significance, 4 demonstrates emphatically more significance, and 5 shows incredibly more significance. The last composite vector of weight coefficients for choices is gotten after the strategy processes and totals their eigenvector. The passages of the last weighted coefficients imply the relative significance (estimation) of every option relating to the objective indicated at the highest point of the pecking order [42,44–46].

A grid A of pairwise comparison is generated by putting the aftereffects of component i with component j into the position a_{ij}, as demonstrated beneath.

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}$$

5.3. Formulation of Structure of AHP

The selection of the most suitable alternative was still not an easy task, specifically when considering sustainability matters. The four main criteria and twelve sub-criteria were carried out i.e., technological, environmental, social, and economic from the literature [8,33,37,38]. TCS, ECS, and BCS are three alternative cookstove technologies to be evaluated for the ranking. Sub-criteria related to each main criterion was also recognized, which is shown in Table 1. After the distinguishing proof of primary standards and sub-standards, the following stage was to decide the general weights of every model and the positioning of the choices of these measures. The weights were carried out by using Expert Choice software. For evaluating the AHP model, the method of eigenvector was used for this study. Figure 6 demonstrates the main steps implicated in this methodology:

While the pairwise correlation could be biased, AHP practices a compatibility test of associations. Equations (1) and (2) represent the way the consistency ratio (CR) and consistency index (CI) are computed correspondingly.

$$CR = \frac{CI}{RI} \tag{1}$$

$$CI = \frac{n_{max} - n}{n - 1} \tag{2}$$

Random index (RI), which expresses the order of a matrix, is presented in Table 3. The acceptable inconsistency level is $CR \leq 0.1$;; however if the inconsistency is higher, i.e., $CR > 0.1$, then to attain better consistency, the decision-maker must re-evaluate the element a_{ij} of A. We calculated the value of n_{max} from,

$$A\overline{w} = n_{max}\overline{w}$$

Table 3. Random consistency index.

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

By observing that the ith equation,

$$\sum_{t=1}^{n} a_{ij}\overline{w}_t = n_{\max}\overline{w}_t \tag{3}$$

where $t = 1, 2, \ldots, n$,

gives,

$$\sum_{i=1}^{n} \bar{w}_t = 1 \tag{4}$$

we obtain,

$$\sum_{i=1}^{n}\left(\sum_{i=1}^{n} a_{ij}\overline{w_t}\right) = n_{max}\sum_{i=1}^{n}\overline{w_t} = n_{max} \tag{5}$$

n_{max} can be calculated by determining a column vector $A\overline{w}$ and afterward calculating the summation of the elements. Furthermore, adding all the criterion's weight and their related weights for each alternative was practiced for the last positioning of choices for the primary standards. The best substitute was one, having the highest rank concerning the main criteria.

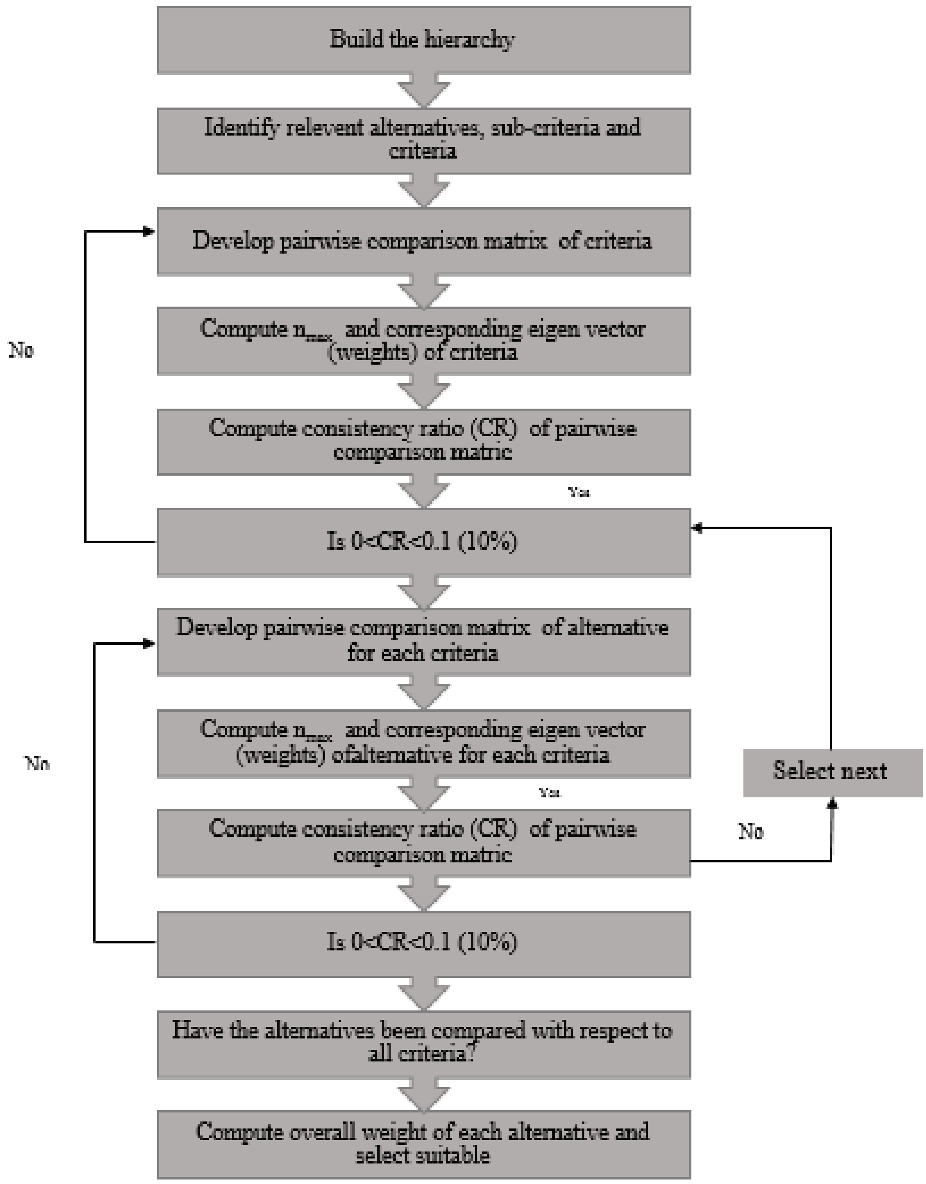

Figure 6. Flowchart of AHP steps.

An AHP model was developed for the selection of cookstoves in Sindh to assess the specific biomass energy technologies. The four main criteria, according to the literature, were categorized. To further improve the model, twelve sub-criteria were identified, giving a direct impact on ranking biomass technologies. The main criteria and sub-criteria of the AHP model are shown in Figure 7. They were recognized from the literature and are appropriate for the energy and environmental system challenges in Pakistan.

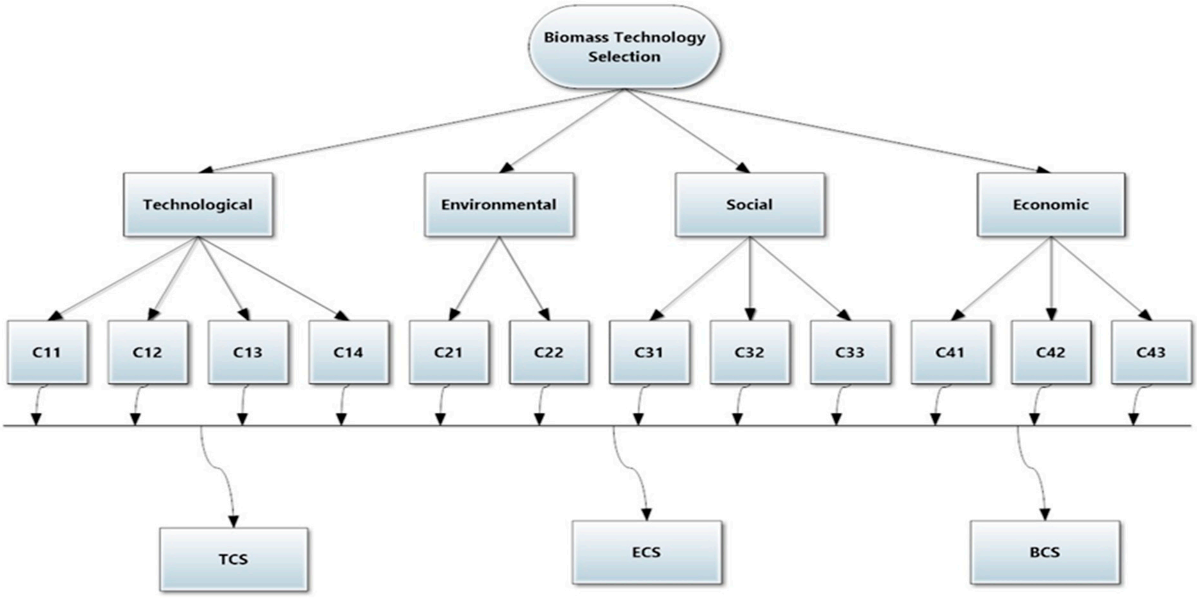

Figure 7. Hierarchy of AHP model.

The AHP model formed for this research comprises of four levels. The goal of the model is at the top level, followed by the criteria at second level. At the third level, sub-criteria are placed and identified as alternatives. At the second level, technical, economic, social, and environmental are considered the four main criteria for this study. Sub-criteria are at level three, and these are given in Figure 6. The fourth level consists of all alternatives for selection of cookstoves by the AHP model. To decide the elements' importance and decision with alternatives, pairwise comparisons were made by using the fundamental scale of the AHP given by Saaty [28], stated in Table 4.

Table 4. Saaty's Likert scaling for identifying intensity of preference.

Intensity of Importance	Definition
1	Equivalent significance
2	Modestly more significance
3	Firmly more significance
4	Emphatically more significance
5	Incredibly more significance

6. Results and Discussion

To acquire the weightage for the criteria and sub-criteria as presented in Figure 7, the females working in rural territories were asked to finish a review through pairwise comparison via Saaty's Likert of 1–5. Further, the stages involved in AHP, as discussed in the above-given flow chart (Figure 6), were achieved by applying the specialist option measuring mechanism, whereby only ten were taken, with the inconsistency of most up to 0.1. The four key criteria were rated by respondents (environmental, economic, social, and technical).

6.1. Computation of Weights of Main Standards

Survey respondents judged the entire fundamental criteria of the study AHP frame, encompassing environmental, economic, socio-politic, and technical for their respective relative importance while using Saaty's scale. Figure 8 denotes the entire prestige achieved by each of the key criteria in percentages.

Technological criteria occupy the highest weight of about 38% out of the four main criteria. Hence, it is the most significant for determining the suitable biomass energy alternatives technology. The other significant criteria were environment, followed by economic and social, respectively.

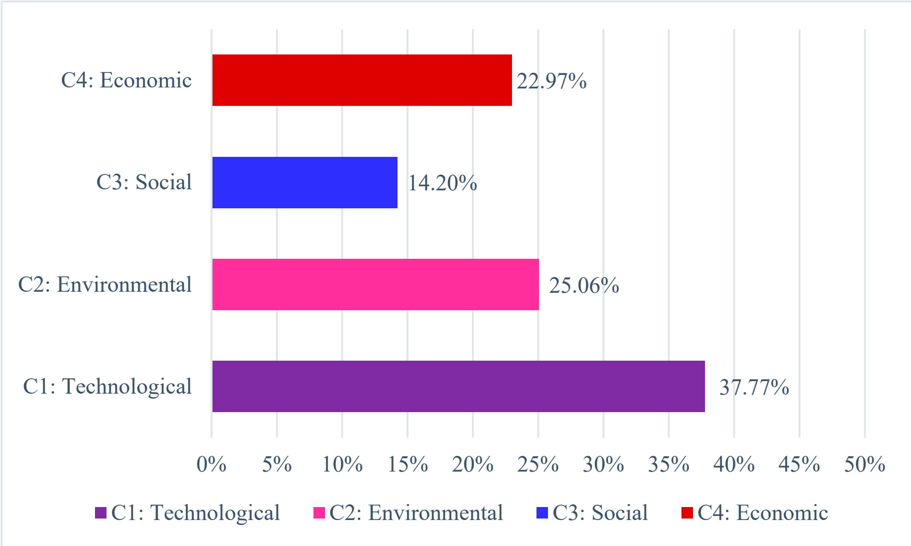

Figure 8. Relative weights of the criteria based on goal.

Computation of Weightages of Sub-Standards

Pairwise comparisons of twelve sub-criteria of this research were conducted, and the resulting weightages are given in Figure 9.

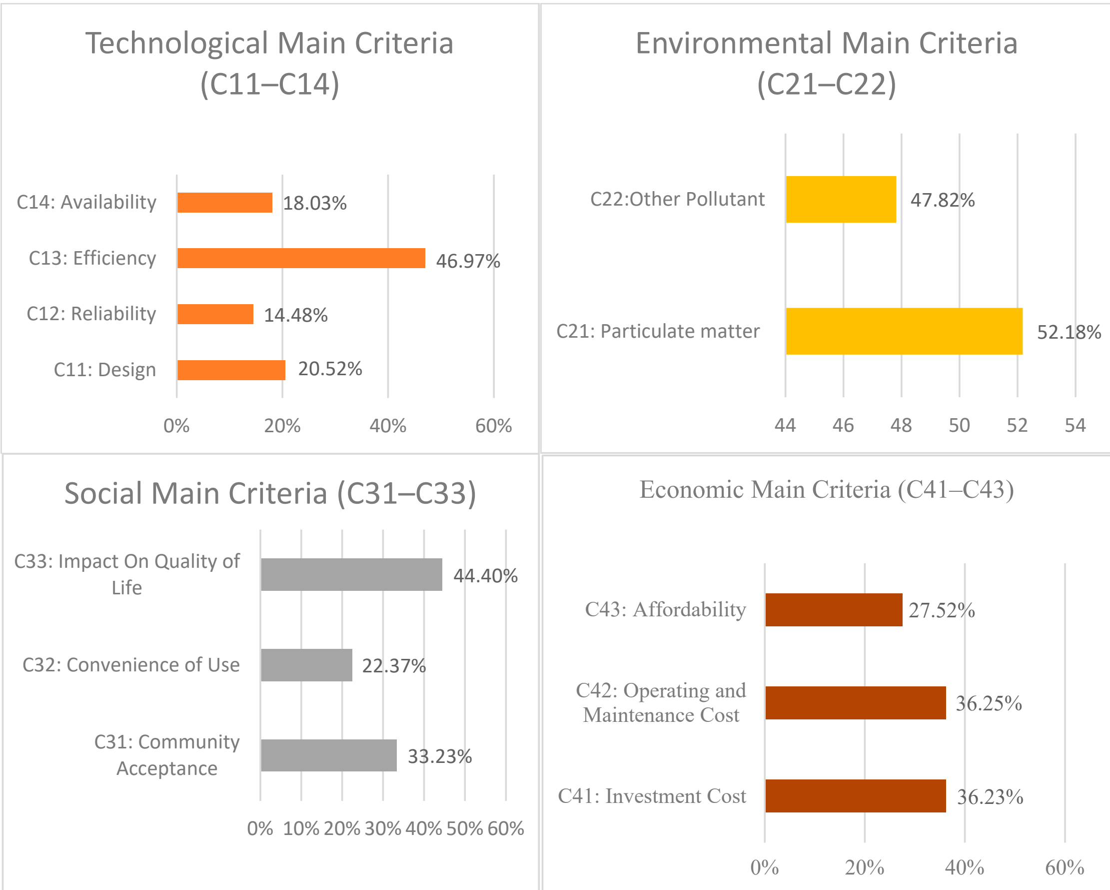

Figure 9. Relative weights of various sub-criteria.

In the technological sub-criteria, a total of four sub-standards were compared pairwise, and results show that the sub-criterion efficiency has accomplished the most noteworthy weightage of about 47%, supported by design, availability, and dependability.

Regarding the environmental sub-criteria, the sub-criterion particulate matter was judged with the highest proportion, approximately about 52.18%, and was followed by other pollutants, as the maximum emission of CO_2 is the indication of increasing consciousness about the hostile repercussions on the universal climate change enigma.

Similarly, in the socio-political sub-criteria, impact on the quality of life has accomplished the most elevated weight of about 44.40%, supported by community acceptance and convenience of use. Moreover, the impact on the quality of life is suggestive of the health and safety issues inside the country and consequently utters the inclination of the overview respondents.

Finally, in the economic sub-criteria, the results exhibit that the sub-criterion operation and maintenance cost was decided as the main one of the financial models, trailed by investment cost and the affordability sub-standards, as depicted in the above portrayal. This evaluation demonstrates the inadequacy of the necessary interests in energy projects, since Pakistan is generally dependent on advances from global financial establishments.

6.2. Concluding Grading of Alternative Technologies

Finally, Figure 10 presents the last weightages of the three elective innovations (BCS, ECS, and TCS) concerning every principal standard (C1–C4).

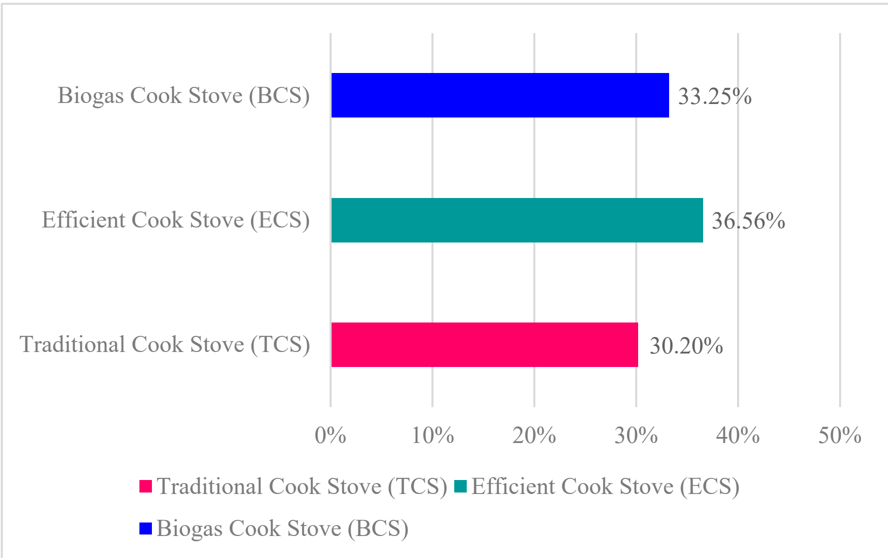

Figure 10. Final ranking of alternative technologies concerning main-criterion.

To check the robustness of the AHP results, it is better to carry out sensitivity analysis; the section below presents the sensitivity analysis of the given results. Sensitivity analysis is important for the justification of these deviations.

7. Sensitivity Analysis

Sensitivity analysis is an examination of the model. Its purposefulness is broadly recognized in the world. The uses are divided into four top divisions: the advancement of suggestions for decision-making, communicating, progressing understanding or quantification of systems, and advancement of models. SA has an uncomplicated thought to switch the model and look at its performance. The present segment encompasses what to switch, what to scrutinize, and lastly, the test design of sensitivity analysis [46].

The final SA results were performed to examine how these results could vary concerning the different views of working women. The coming part formally progresses with the study's sensitivity analysis.

7.1. Dynamic Sensitivity Analysis

Dynamic sensitivity analysis shows that the changes in priorities from one main criteria to the other impact the rankings of the alternatives of the present study. The following section elaborates on the changes in the main criteria and their effects on the actual results.

7.1.1. Scenario Alternative 1

First, the dynamic sensitivity analysis of the actual results was examined. The determined weights of the total criteria considering all alternatives is shown in Figure 11. Given results show that technological criteria (C1) gained the highest weightages, and ECS was the most favored alternative.

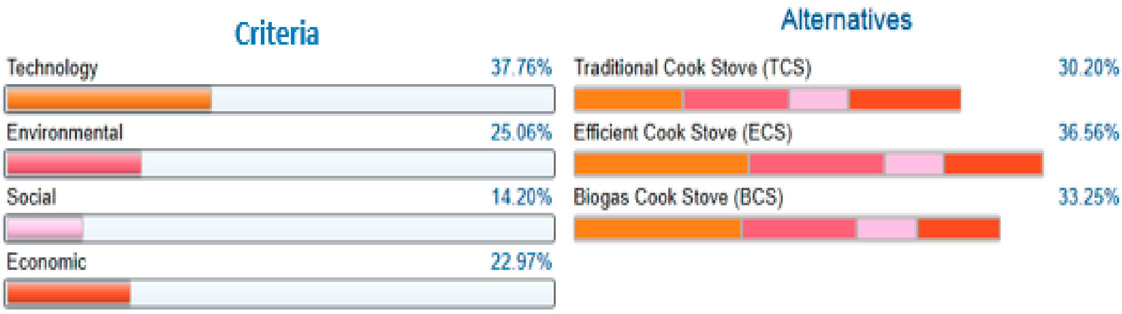

Figure 11. Dynamic sensitivity analysis of the actual results for Scenario Alternative 1.

7.1.2. Scenario Alternative 2

By considering environmental (C2) as the highest weight (38%) which transformed the weightages of other main criteria correspondingly, it was noticed there were not any major changes. Assigning the highest weight to the main criteria C2 is shown in Figure 12.

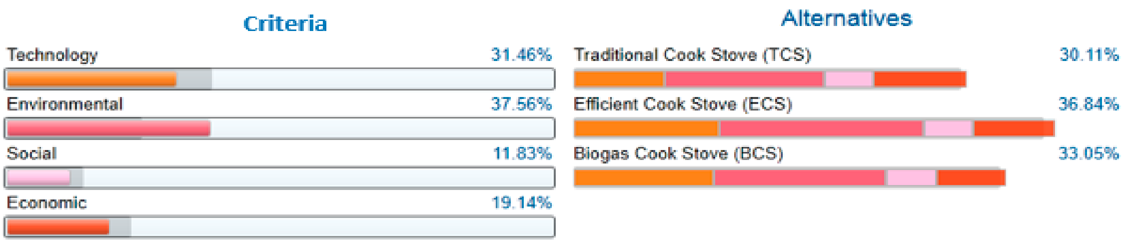

Figure 12. Dynamic sensitivity analysis of the results for Scenario Alternative 2.

7.1.3. Scenario Alternative 3

Further, when the social criterion had been allotted the highest weight (38%), the weightages of other criteria were also altered, though they did not give any intricate changes, as depicted in Figure 13.

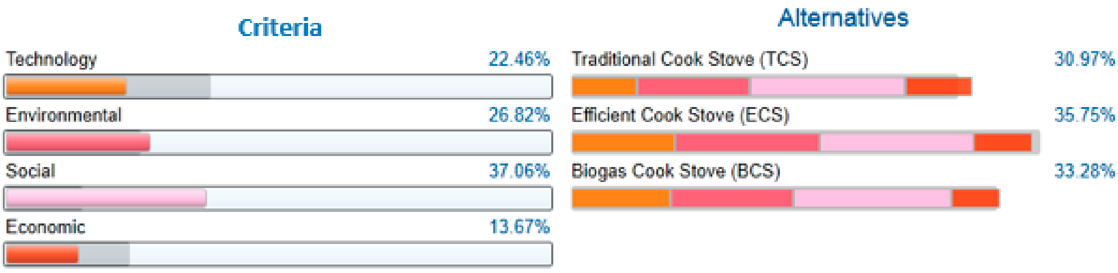

Figure 13. Dynamic sensitivity analysis of the results Scenario Alternative 3.

7.1.4. Scenario Alternative 4

In this way, the criterion economic (C4) had been allocated the maximum weight (38%), which changed the weights of the other criteria. It was again observed that after changing the actual weightage of the economic criterion, the ranking of the results remained same as the actual ranks, as shown in Figure 14.

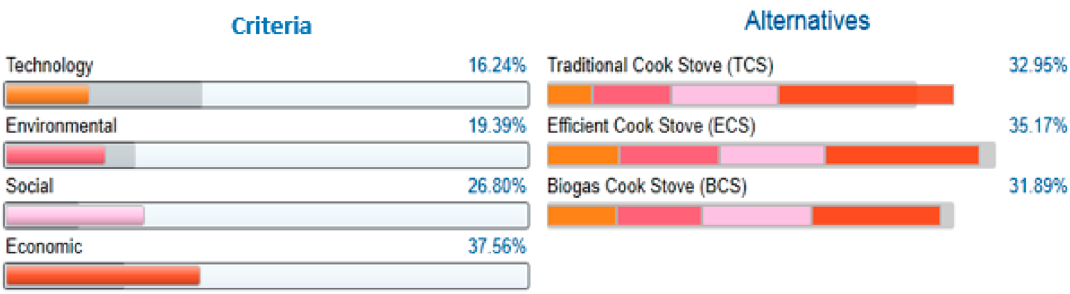

Figure 14. Dynamic sensitivity analysis of the actual results Scenario Alternative 4.

7.1.5. Scenario Alternative 5

Finally, approximately equal weights were allotted to all main criteria (25%). However, the ranking remained the same as the actual results, as Figure 15 shows.

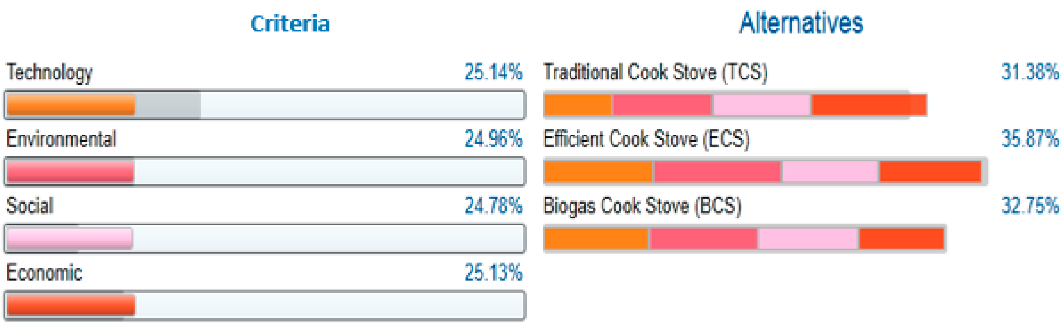

Figure 15. Dynamic sensitivity analysis of the actual results Scenario Alternative 5.

From the above changes, it is evident that dynamic sensitivity analysis shows that if the preference of one standard alters, the weights of another criterion fluctuate too. Moreover, some preferences regarding alternatives are reduced or risen in contrast to the actual values, though the ranking remained unaffected in all perspectives (Figures 11–15), which demonstrates the robustness of the AHP results of the study.

7.2. Performance Sensitivity Analysis

An exhibition investigation diagram shows that one option is best on each levelheaded and each sub-objective! This is an indication of either a trifling choice or a more probable a sign that something was neglected.

The general inclination attributed to every alternate option via those respondents is emphasized in the performance sensitivity analysis for each main criterion. Though the performance of the ECS was more suitable among all criteria, followed by BCS and TCS, the main criteria technology was considered very consistent in all criteria, as shown in Figure 16.

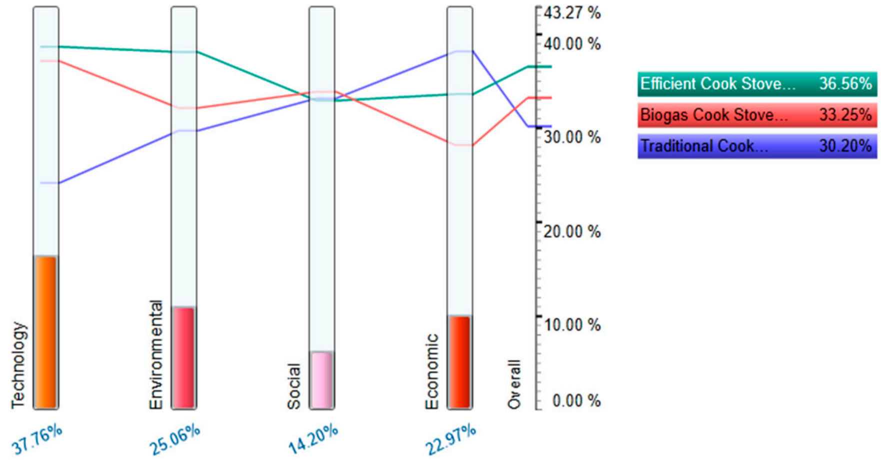

Figure 16. Performance sensitivity analysis of alternative, with respect to the main criteria.

Performance Sensitivity of Alternatives on Sub-Criteria

Figure 17 Shows the performance sensitivity analysis of all sub-criteria, with weightages for all alternatives. It can be observed from the results that overall, the performance of the ECS is the highest, although in few sub-standards, it is not considerable, such as for availability (C14) and affordability (C34). This reflects the respondents' views about the preferable alternatives. For the biogas, which is ranked as second, performance is overall good, except for the affordability (C34). Furthermore, the third-ranked alternative is low in many sub-objectives, as compared to the ECS and BCS, as shown in Figure 17.

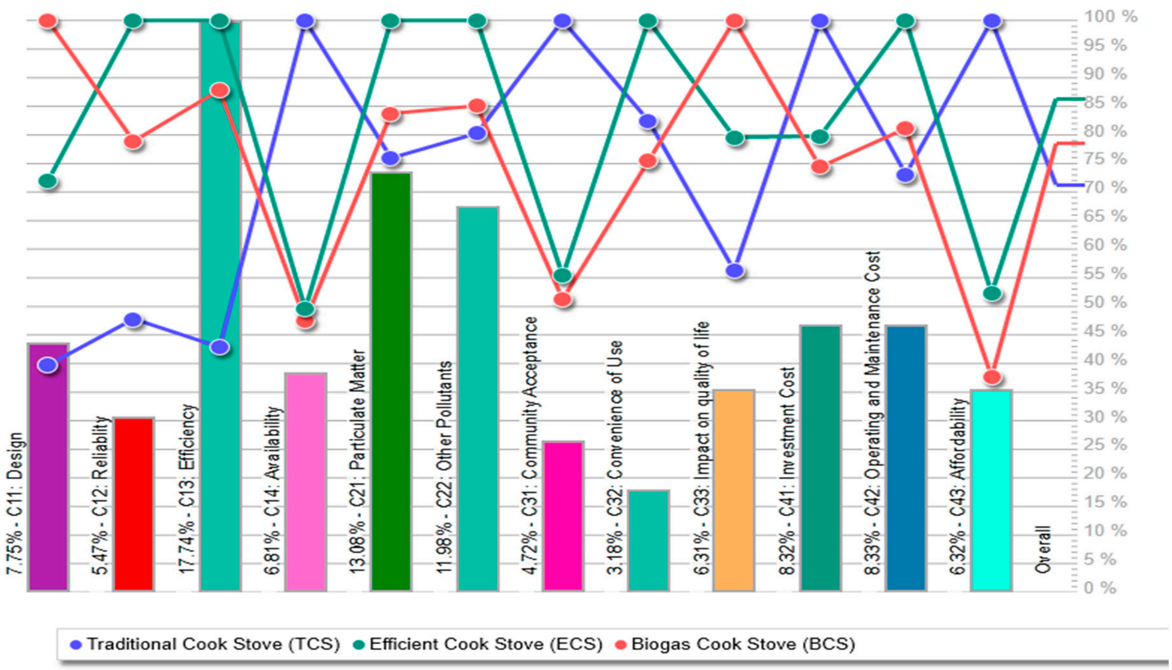

Figure 17. Performance sensitivity analysis of alternatives with respect to all sub-criteria.

The results of the ongoing study facilitate respondents with an insight into stove technology. Additionally, the AHP reveals the last classification, regarding alternatives, that the ECS-based cooking stove has reached the most leading counterweight. The ESC has been top ranked, having a weight of 38.67%. In contrast, the BCS ranked second, with a weightage of 37.14%. In comparison, the TCS stands third, by weighing 24.18% based on principal criteria. On environmental standards, the ESC stands at the top, with 38.11%, whereas the BCS is second, with 32.16%, and TCS is third, with 29.13%.

Furthermore, the BCS has a proportion of 33.89%, with the highest value for the social criteria, and the TCS has the second-highest ratio of 33.18%. Similarly, the ESC stands at third, with a weightage of 32.93%. On economic criteria, the TCS has obtained the utmost weight, around 38.16%, whereas the ECS and BCS appeared at second and third, with the weightage of 33.63% and 28.22%, respectively, as depicted in the appendix. Furthermore, under the final ranking matrix, the ECS alternative got the highest weightage, nearly 36.56%, based on the developed hierarchal (AHP) model.

The outcome of this study has speculated that the ECS cookstove technology is the preferred measure for biomass energy in the Sindh province of Pakistan. Thus, investment and era distribution should make the lives of ordinary people dwelling in rural areas thrive.

8. Conclusions

Effective utilization of energy resources is achieving prominent significance. This study focuses on biomass, an energy resource, for choosing a suitable cookstove. For that, an AHP model was developed. The developed model revealed its results and suggested that the principal criteria is the economic criteria, which is the most essential and fundamental standard in opting for technologies, as per the survey respondents. This study estimated three choices and conclusively, it is the ECS that is considered as the most predominated technology to be acquired, followed by BCS and TCS, respectively. The ECS alternative got the highest weightage, nearly 36.56%, based on the developed model in the sensitivity analysis. Acceptance of technologies was based on various standards and sub-standards, but the economic criteria determined the prioritization of technology in adopting suitable cookstoves among all measures. The ECS was observed to be the most reasonable innovative technology and ought to be made accessible in rural regions. Lastly, the respondents claimed numerous extra advantages, including that, comparatively, ECS has low fuelwood consumption and subsequently lower monetary expenditures for fuel, practical cooking with reduced particulate matter, and low external health and environmental hazards.

Author Contributions: Conceptualization, H.S.; methodology, H.S., L.K.; software, H.S., L.K.; validation, H.S., L.K. and K.H.; formal analysis, S.F.S., L.K., J.D.N. and K.H.; investigation, H.S., J.D.N., K.H.; resources, S.F.S., K.H.; data curation, H.S., K.H.; writing—original draft preparation, H.S.; writing—review and editing, S.F.S., W.S.S., J.D.N. and K.H.; supervision, S.F.S., M.A.U.; project administration, S.F.S., M.A.U., J.D.N. and K.H.; funding acquisition, W.S.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors would also like to acknowledge the Higher Education Commission, the Government of Pakistan, and the British Council for supporting this study under the Knowledge Economy Partnership Project (KEP-PK-046).

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

TCS	Traditional Cook Stove
ECS	Efficient Cook Stove
BCS	Biogas Cook Stove
MCDM	Multicriteria Decision Making
MADM	Multi-Attribute Decision Making
AHP	Analytical Hierarchy Process
CR	Consistency Ratio
CI	Consistency Index
RISA	Rando Index Sensitivity Analysis

References

1. Chaudhry, M.A.; Raza, R.; Hayat, S. Renewable energy technologies in Pakistan: Prospects and challenges. *Renew. Sustain. Energy Rev.* **2009**, *13*, 1657–1662. [CrossRef]
2. Hussain Mirjat, N.; Uqaili, M.A.; Harijan, K.; Mustafa, M.W.; Rahman, M.; Khan, M. Multi-criteria analysis of electricity generation scenarios for sustainable energy planning in Pakistan. *Energies* **2018**, *11*, 757. [CrossRef]
3. Bhutto, A.W.; Bazmi, A.A.; Zahedi, G. Greener energy: Issues and challenges for Pakistan—Biomass energy prospective. *Renew. Sustain. Energy Rev.* **2011**, *15*, 3207–3219. [CrossRef]
4. Amer, M.; Daim, T.U. Selection of renewable energy technologies for a developing county: A case of Pakistan. *Energy Sustain. Dev.* **2011**, *15*, 420–435. [CrossRef]
5. Limmeechokchai, B.; Chawana, S. Sustainable energy development strategies in the rural Thailand: The case of the improved cooking stove and the small biogas digester. *Renew. Sustain. Energy Rev.* **2007**, *11*, 818–837. [CrossRef]
6. Association, A.L. Pakistan GDP and Population of Pakistan (2020 and Historical). (2019–2020). Available online: https://www.worldometers.info (accessed on 1 June 2021).
7. GOP. *Area, Population, Density and Urban/Rural Proportion*; Statistics, P.B.O., Ed.; 2020. Available online: http://www.pbs.gov.pk/ (accessed on 1 June 2021).
8. Prajapati, A.; Nakarmi, A.M. Performance Evaluation of Energy Technologies in Residential Sector. In Proceedings of the IOE Graduate Conference, Nepal; 2014; p. 119. Available online: http://conference.ioe.edu.np/publications/ioegc2014/IOEGC-2014-Coverpage.png (accessed on 1 June 2021).
9. Government of Pakistan Ministry of Statistics. *Population_Results*; Pakistan Bureau of Statistics: Islamabad, Pakistan, 2017.
10. US Energy Information Administration. *Electricity Data Browser*; US Energy Information Administration: Washington, DC, USA, 2017.
11. Tareen, W.U.K.; Dilbar, M.T.; Farhan, M.; Ali Nawaz, M.; Durrani, A.W.; Memon, K.A.; Mekhilef, S.; Seyedmahmoudian, M.; Horan, B.; Amir, M. Present Status and Potential of Biomass Energy in Pakistan Based on Existing and Future Renewable Resources. *Sustainability* **2020**, *12*, 249. [CrossRef]
12. Nakarmi, A.M.; Mishra, T.; Banerjee, R. Integrated MAED–MARKAL-based analysis of future energy scenarios of Nepal. *Int. J. Sustain. Energy* **2016**, *35*, 968–981. [CrossRef]
13. Janjua, N.; Mahmood, B.; Dharma, V.; Sathiakumar, N.; Khan, M.I. Use of biomass fuel and acute respiratory infections in rural Pakistan. *Public Health* **2012**, *126*, 855–862. [CrossRef]
14. Raza, M.Y.; Wasim, M.; Sarwar, M.S. Development of Renewable Energy Technologies in rural areas of Pakistan. *Energy Sources Part A Recovery Util. Environ. Eff.* **2020**, *42*, 740–760. [CrossRef]
15. Mirza, U.K.; Ahmad, N.; Majeed, T. An overview of biomass energy utilization in Pakistan. *Renew. Sustain. Energy Rev.* **2008**, *12*, 1988–1996. [CrossRef]
16. UNEP. Environmental Effects of Ozone Depletion 1998 Assessment. Available online: http://cedadocs.ceda.ac.uk/984/1/Environmental-Effects-Assess98.pdf (accessed on 1 June 2021).
17. Kumar, S.; Harijan, K.; Jeguirim, M.; Soomro, M.I.; Nixon, J.D.; Uqaili, M.A. Assessment of energy potential of date palm residues in Khairpur district, Pakistan. *Biofuels* **2019**, *12*, 599. [CrossRef]
18. Harijan, K.; Uqaili, M.A. Potential of biomass conservation through dissemination of efficient cook stoves in Pakistan. *APCBEE Procedia* **2013**, *5*, 358–362. [CrossRef]
19. Khan, J.; Harijan, K.; Uqaili, M.; Gillmore, G.; Nixon, J. 269. Municipal Solid Waste to Energy in Pakistan: A Case Study of Haripur District (Pakistan). Master's Thesis, Kingston University, London, UK, 2016.
20. Khushk, W.A.; Fatmi, Z.; White, F.; Kadir, M.M. Health and Social Impacts of Improved Stoves on Rural Women: A pilot intervention in Sindh, Pakistan. *Indoor Air* **2005**, *15*, 311–316. [CrossRef] [PubMed]
21. Yaseen, M.; Abbas, F.; Shakoor, M.B.; Farooque, A.A.; Rizwan, M. Biomass for renewable energy production in Pakistan: Current state and prospects. *Arab. J. Geosci.* **2020**, *13*, 1–13. [CrossRef]
22. Kandhro, B.; Sahito, A.R.; Nixon, J.D.; Uqaili, M.A.; Mirjat, N.H.; Harijan, K.; Zaman, R.O.; Kumar, L. Seasonal variation in biogas production in reinforced concrete dome biogas plants with buffalo dung in Pakistan. *Biomass Convers. Biorefinery* **2022**, 1–15. [CrossRef]

23. Johnson, N.G.; Bryden, K.M. The Impact of Cookstove Adoption and Replacement on Fuelwood Savings. In Proceedings of the Global Humanitarian Technology Conference (GHTC), Seattle, WA, USA, 21–24 October 2012; pp. 387–391.
24. Bhattacharya, S.; Salam, P.A. Low greenhouse gas biomass options for cooking in the developing countries. *Biomass Bioenergy* **2002**, *22*, 305–317. [CrossRef]
25. Wu, Q.; Zou, D.; Zheng, X.; Liu, F.; Li, L.; Xiao, Z. Effects of antibiotics on anaerobic digestion of sewage sludge: Performance of anaerobic digestion and structure of the microbial community. *Sci. Total Environ.* **2022**, *845*, 157384. [CrossRef]
26. Zheng, X.; Zou, D.; Wu, Q.; Wang, H.; Li, S.; Liu, F.; Xiao, Z. Review on fate and bioavailability of heavy metals during anaerobic digestion and composting of animal manure. *Waste Manag.* **2022**, *150*, 75–89. [CrossRef]
27. Milan, Z. *Multiple Criteria Decision Making*; Springer Science & Business Media: New York, NY, USA, 1982.
28. Saaty, T.L. How to make a decision: The analytic hierarchy process. *Eur. J. Oper. Res.* **1990**, *48*, 9–26. [CrossRef]
29. Antonopoulos, I.-S.; Perkoulidis, G.; Logothetis, D.; Karkanias, C. Ranking municipal solid waste treatment alternatives considering sustainability criteria using the analytical hierarchical process tool. *Resour. Conserv. Recycl.* **2014**, *86*, 149–159. [CrossRef]
30. Siksnelyte-Butkiene, I.; Zavadskas, E.K.; Streimikiene, D. Multi-criteria decision-making (MCDM) for the assessment of renewable energy technologies in a household: A review. *Energies* **2020**, *13*, 1164. [CrossRef]
31. Lak Kamari, M.; Isvand, H.; Alhuyi Nazari, M. Applications of Multi-Criteria Decision-Making (MCDM) Methods in Renewable Energy Development: A Review. *Renew. Energy Res. Appl.* **2020**, *1*, 47–54.
32. Ahmad, S.; Tahar, R.M. Selection of renewable energy sources for sustainable development of electricity generation system using analytic hierarchy process: A case of Malaysia. *Renew. Energy* **2014**, *63*, 458–466. [CrossRef]
33. Luthra, S.; Kumar, S.; Garg, D.; Haleem, A. Barriers to renewable/sustainable energy technologies adoption: Indian perspective. *Renew. Sustain. Energy Rev.* **2015**, *41*, 762–776. [CrossRef]
34. Ren, J.; Sovacool, B.K. Prioritizing low-carbon energy sources to enhance China's energy security. *Energy Convers. Manag.* **2015**, *92*, 129–136. [CrossRef]
35. Confino, J.; Paddison, L. Cookstove Designs Are Failing the Poorest Communities. Available online: http://www.theguardian.com/sustainable-business/cookstoves-design-poorcommunities-refugees-unhcr-ikea (accessed on 1 June 2021).
36. Fatmi, Z.; Rahman, A.; Kazi, A.; Kadir, M.M.; Sathiakumar, N. Situational analysis of household energy and biomass use and associated health burden of indoor air pollution and mitigation efforts in Pakistan. *Int. J. Environ. Res. Public Health* **2010**, *7*, 2940–2952. [CrossRef]
37. Dasgupta, S.; Huq, M.; Khaliquzzaman, M.; Pandey, K.; Wheeler, D. Who suffers from indoor air pollution? Evidence from Bangladesh. *Health Policy Plan.* **2006**, *21*, 444–458. [CrossRef]
38. Dasgupta, S.; Wheeler, D.; Huq, M.; Khaliquzzaman, M. Improving Indoor Air Quality for Poor Families: A controlled Experiment in Bangladesh. *Health Policy Plan.* **2009**, *19*, 22–32. [CrossRef]
39. Ezzati, M.; Mbinda, B.M.; Kammen, D.M. Comparison of emissions and residential exposure from traditional and improved cookstoves in Kenya. *Environ. Sci. Technol.* **2000**, *34*, 578–583. [CrossRef]
40. Naeher, L.; Leaderer, B.P.; Smith, K.R. Particulate matter and carbon monoxide in highland Guatemala: Indoor and outdoor levels from traditional and improved wood stoves and gas stoves. *Indoor Air* **2000**, *10*, 200–205. [CrossRef] [PubMed]
41. Jeuland, M.A.; Pattanayak, S.K. Benefits and costs of improved cookstoves: Assessing the implications of variability in health, forest and climate impacts. *PLoS ONE* **2012**, *7*, e30338.
42. Khodaparast, M.; Rajabi, A.M.; Edalat, A. Municipal solid waste landfill siting by using GIS and analytical hierarchy process (AHP): A case study in Qom city, Iran. *Environ. Earth Sci.* **2018**, *77*, 52. [CrossRef]
43. Velasquez, M.; Hester, P.T. An analysis of multi-criteria decision making methods. *Int. J. Oper. Res.* **2013**, *10*, 56–66.
44. Darko, A.; Chan, A.P.C.; Ameyaw, E.E.; Owusu, E.K.; Pärn, E.; Edwards, D.J. Review of application of analytic hierarchy process (AHP) in construction. *Int. J. Constr. Manag.* **2019**, *19*, 436–452. [CrossRef]
45. Saranya, T.; Saravanan, S. Groundwater potential zone mapping using analytical hierarchy process (AHP) and GIS for Kancheepuram District, Tamilnadu, India. *Model. Earth Syst. Environ.* **2020**, *6*, 1–18. [CrossRef]
46. Yap, H.; Nixon, J. A multi-criteria analysis of options for energy recovery from municipal solid waste in India and the UK. *Waste Manag.* **2015**, *46*, 265–277. [CrossRef]