Multiple criteria decision making FAHP Model of Renewable Energy Sources Planning for Sustainable Development Egypt case study

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Abstract

Sustainable development has become one of the most popular terms in the last few decades, which can be attributed to several issues: depletion of fossil fuels, global warming and climate change concerns. This heightened the importance of energy security and efficiency to achieve sustainable development and all-inclusive growth. Energy is a crucial component of sustainable development. It is an essential factor in driving production, achieving stability and economic growth, creating jobs, improving living standards and reducing poverty.

The need for alternative energy sources was inevitable. Following the global trend to use renewable energy, Egypt is moving further towards the transition to clean energy.

Multi-criteria Decision-making (MCDM) process such as the Analytic Hierarchy Process (AHP) and Fuzzy Analytic Hierarchy Process (FAHP) have been used to solve many decision-making problems. After thoroughly examining the country's potential for renewable energy sources, a FAHP model was developed to prioritize renewable energy sources in Egypt. This methodology is expected to help policymakers to identify what is the most suitable renewable energy source that could contribute to Egypt's sustainable development strategy.

Keywords: Renewable Energy, MCDM, FAHP, Sustainable Development, Egypt, AHP

1. Introduction

Energy is an extremely valuable resource that, if used wisely, will result in economic development and meet its population growth. In most emerging countries, energy consumption has significantly increased throughout the years to meet the continuous increase in energy demand which led to the increasing pressure on the economic system.

Egypt launched its sustainable development strategy for the year 2030. The strategy restricts the economic development plans to achieve certain standards of sustainability. The target here is to become a leader by efficient energy use and renewable energy development. Moreover, the country also revealed its expectations to increase the contribution of energy to the GDP by not only producing renewable energy but also by exporting it to other countries. (MOPIC, 2015)

Egypt has many governmental entities such as the ministry of petroleum (MOP), and the ministry of electricity and renewable energy. In addition to other ministries that have a significant impact on the Egyptian energy system which include the ministry of industry and ministry of transportation. How could Egypt government manage its energy policy?, it will be difficult to determine the extent of which energy sources will truly deal with challenges related to climate change, environment, population, and economic growth. Hence, the need for a decision-making approach is crucial.

The general aim of this study could be summarized as follows;

i) To Illustrate and shed-light on the most important aspects of the energy sector in Egypt

ii) Define the main criteria and sub-criteria that could be used to prioritize renewable energy sources with respect to sustainable development goals, and use FAHP as one of MCDM methods.

iii) Prioritizing renewable energy sources to find out the best renewable energy source that could effectively contribute to Egypt's sustainable development strategy.

2. Egypt’s Energy Sources and Renewable Energy Potential

Egypt is one of Africa’s main oil and gas producers. It is number one Non-OPEC oil producer and largest energy consumer in Africa, number two Gas producer in Africa and is ranked number 15th largest Gas producer worldwide. (EIA, 2018)

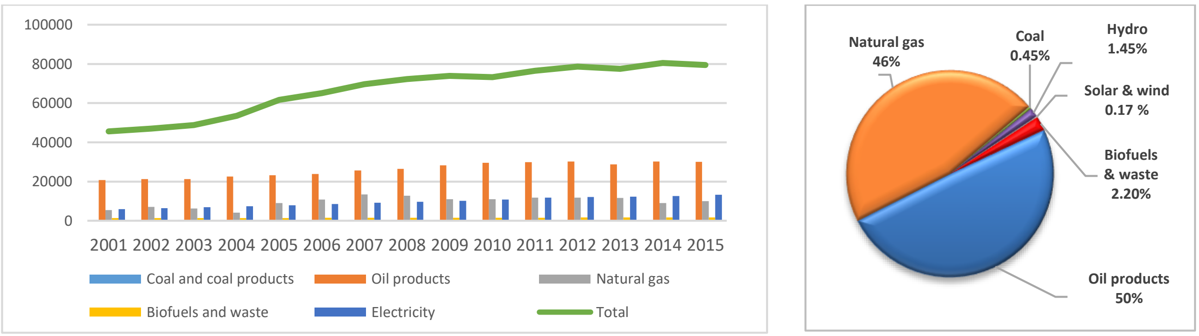


Figure 1 Share of total primary energy supply Ktoe 2015 (IEA, 2015)

2. 1 New and Renewable Energy Sources in Egypt

2.2.1 Wind

According to wind atlas of Egypt 2005, the average wind speed reaches 10.5 M/sec at 50 m height and 7.5 m/s at 80 m height. Thus, the potential capacities of power production are more than 30000 MW. Recently the installed capacity is around 750 Mw the generated energy is around 12.6 Billion KWh which was reduced to around 6.8 million ton of CO_2. Farther 3000 Mw could be developed in East of Nile (CTF, 2009)

The KWh price produced from wind power plants LCOE lies between 0.047 and 0.079 $/kWh (Average 0.063 $/kWh), since the CAPEX varies between 1100 $/kWp and 1600 $/KWp (Average 1350 $/KWp). (Noha Saad Hussein, 2016)

2.2.2 Solar

Solar atlas of Egypt the high potential of solar energy with direct solar radiation ranging from 2000 – 3200 KWH/m^2/year and sunshine duration 9 to 11 hour per day. It also shows the potential capacities of more than 50000 MW produced power (MOEE, 2018)

Concentrated Solar Power (CSP) installed capacity 140 MW and photovoltaic 80 MW. According to earlier solar power studies, Egypt can greatly increase its potential installed capacity to 50000 MW. (Salem, 2017), Egypt’s solar thermal electricity has been estimated at 73,656 terawatt-hours (TWh)/year which is transformed into several thousand MWs of installed capacity

The KWh price produced from utility-scale plants lies between 0.079 and 0.123 $/kWh (0.101 $/KWh average), since the CAPEX varies between 1200 $/kWp and 1500 $/WP (1350 $/WP average). (Noha Saad Hussein, 2016)

2.2.3 Hydro

In 2015, Hydropower installed capacity was around 8% of Egypt's electric power generation, 2850 MW approximately from total 2016 generation mix. This amount comes from High dam and other small hydro plants that have already been developed. Most of the Hydropower potential of Egypt has already reached around 85% from the Nile River and from Aswan High Dam and some Reservoir Dams. Recently, there is a new project under construction about 32 MW. This project, located in Assuit Governorate, is planned to build a pumping-storage plant nearby with 2400 MW capacity to be operated by 2020 to reduce the high peak load impact and to benefit from many wind and solar power plants nearby (Elkhayat, 2016),

According to the world energy council report published in 2016, hydropower installed capacity reached 2800 MW in 2015 with an estimated net hydropower generation about 13700 GWh. Technically feasible hydro generation potential can reach 50000 GWh, (WEC, 2016)

2.2.4 Biomass

There is a great potential to benefits from biomass energy in Egypt. Despite considering biogas as a renewable energy source, it is used inefficiently such as agriculture residues which are used as a combustion source for open fire stoves in rural areas, (MS, 2009). Egypt, according to World Energy Organization, had a municipal waste around 2.4 million tons in 2002 which can provide around 18000 KW of electricity, 1.4 million tons sugar cane bagasse produce ethanol of 456 Tj/yr, additional source comes from biodiesel production which increases the total capacity to 479.83 Tj. Animal dung reaches 6 million tons which produce 40 TJ/yr (WEC, 2016).

Table 1 Theoretical potential energy from biomass residues in Egypt

No.	Biomass type	Theoretical Potential energy per (Pj)	Percentage of total energy (%)
1	Agricultural crop residues	185.75	44.6
2	Animal wastes (cows and buffalo)	40.61	9.7
3	Sewage waste	16.74	4
4	Municipal solid waste	173.8	41.7
Total		416.9	100

From the previous review subtitle 2.4, new and renewable energy sources, *Table 2* illustrates the different renewable energy sources potential capacity MW in Egypt.

Table 2 potential capacity from renewable energy sources in Egypt

Renewable energy sources potential installation capacity MW; Egypt case			
Wind	Solar	Biomass	Hydro
30000	50000	416.9 (Pj)	8000

3. Literature Review

3. 1 Multi-Criteria Decision-Making using AHP and FAHP

The concept of MCDM became crucial since individuals, organizations, and states who face many problems whose solution has several objectives. Consequently, several criteria should be taken into account during the decision- making process rather than a single criterion or one goal. AHP method was developed by Thomas L. Saaty in the '70s of the last century. Since then, AHP is commonly used for MCDM and has been successfully applied to many decision-making issues (Saaty, 2000). MCDM, well-known for multiple-criteria decision making and decision analysis, is a set of specific decision-making criteria facing a decision-maker to select between the available alternatives for solving a specific problem or prioritizing a small set of goods or best alternatives. (MCDM, 2018)

3.1.1 Analytic Hierarchy Process (AHP)

The process of decision-making using AHP developed by Saaty to generate priorities should follow these steps; first define the main problem and determine a set of criteria that influences the prime objective, second from the goal of decision structure the decision hierarchy then the criteria and at the lowest level the alternatives, third construct the set of pairwise comparison matrices, finally use the priorities result from the comparison to set weigh, and obtain final alternatives priorities of alternatives. (Saaty, 2008)

The priority setting is to make pairwise comparisons between the second levels in the hierarchy with values ranging from 1 to 9. (Saaty, 2008)

3.1.2 Fuzzy Analytic Hierarchy Process (FAHP)

The main advantage of the fuzzy analytical hierarchy process FAHP method over the standard AHP method is to apply the pair-wise comparison using linguistic variables that are more familiar to the decision-makers DM’s. The inconsistency ratio ICR will be calculated in the same manner as in the standard AHP;

3. 2 RE Criteria/ Sub-criteria for Sustainable Energy Development

Sustainability now becomes the biggest challenge in 21st century. The concept and term of sustainable development emerged as a natural response to the risk of environmental degradation resulting from the traditional mode of development, which is based on the rapid growth of production without regard to the negative effects that this development has on human beings, natural resources and the environment. (Orecchini, 2011).

3.2.1 Sustainable Development Criteria

UNEP's framework states that the road to sustainability needs to address at least three key principles; economic, social, and environmental dimensions. (UNEP, 2015)

Social Dimension; defined as the natural human right to live in a clean environment through which all his or her activities are exercised while ensuring the right to a fair share of natural resources, environmental and social services, and complementary needs to raise the standard of living.

Environment Dimension; means the ability of natural resources and environment to meet the current needs without degradation or depletion, only to the extent that it does not threaten future generations. The concept of environmental sustainability is to leave the earth in good condition for future generations.

Economic Dimension; the cost of the development for the present societies must be highly cost-effective, and does not lead to transferring these costs and their expense to the future generations. The time factor is an important factor in the development process by setting plans and timetables to achieve needs for long and different periods of time.

Technical Dimensions; since the technical issues such as technology maturity and resource availability are very important to evaluate energy resources, however, many technical criteria have been used in the previous research such as safety, reliability, and efficiency.

3.2.2 Sub-criteria for Renewable Energy Sources

Previous work has been done using MCDM and AHP, in a selection of renewable energy sources or energy alternatives overall, four main criteria were used in sustainable energy planning by policymakers or energy researchers, economic, social, environment and technical. Each main criteria can be described by many sub-criteria, in the following table we will identify the most frequent criteria used in energy issues.

Table 3 most frequently used Criteria and sub-criteria in sustainable renewable energy planning

Criteria	Sub-criteria	Description
Economic	Investment cost	Cost of purchase all equipment, engineering, construction Etc.
	Electric cost	The cost of producing one KWh, or levelized cost of electricity (LCOE)
Social	Social acceptance	The lack of social acceptance can cancel or delay any project, acceptability here means the opinion of residents, stakeholders and other authorities of any project
	Job creation	How many job opportunities generated from energy project, projects which create more jobs considered more beneficial for local communities
Environment	GHG Emissions	The calculated amount of greenhouse gases could be avoided by using RE
	Land requirement	Any renewable energy project needs land which affects the landscape and increases the capital cost of the project or may affect the other activates especially near to the urban areas
Technical	Technology maturity	Means how specific technology widely spread at the national and international level, or still under development, it could be also the technologies need to operate RE projects
	Resource availability	Availability of deferent renewable energy sources or the potential generation capacity
References	*(Mardani Abbas, 2015), (Brahim Haddad, 2016), (Muhammad Amer, 2011), (Lee AHI, 2008), (Mateo, 2012), (Yung Chi Shen, 2010), (Salman Ahmad, 2013), (Joseph Daniel, 2010), (Murat Çolaka, 2017).*	

4. Methodology

4. 1 Procedure for FAHP, MCDM Model

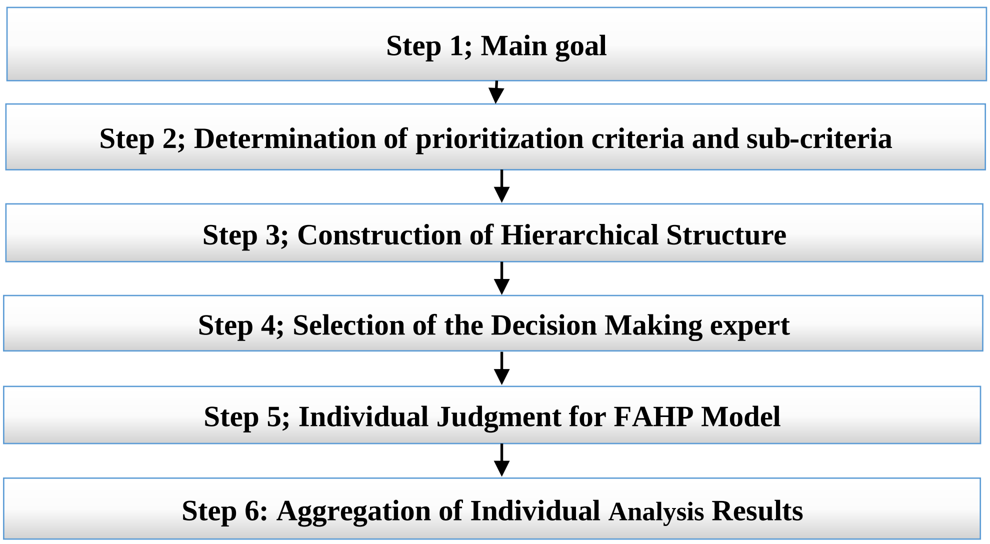


Figure 2 procedure of FAHP-Based model for prioritizing RE sources

4. 2 Selected Sub-Criteria Benchmark

The evaluation criteria and their sub-criteria represent the intermediate levels of the hierarchy. Therefore, in addition to studying much related literatures and referring to some similar studies, the evaluation criteria were determined through several interviews and discussions with Egyptian experts in the energy industry with experience in renewable energy.

In order to improve the results of the research survey, it was important to take into consideration the different level of experience and knowledge for the participants towards the technical criteria used in the assessment process of renewable energy sources in Egypt. Hence, provide the subject-matter expert (SME), clear figures about those applied criteria to be considered before starting the evaluation process and pairwise comparisons for renewable sources alternatives. *Table 4* is the fact sheet that will be used as a guide for selected subject-matter expert (SME) during conducting the pairwise comparison.

Table 4 Renewable Energy Sub-criteria for Sustainable Development Fact Sheet

No		Sub-criteria	Wind	Solar	Hydro	Biomass	Ref
1	Economic	**Capital cost** USD $/KW	1300 ~ 2900	900 ~ 3800	800 ~ 4000	1100 ~ 4900	(IRENA, 2018)
2		**KWh price** USD $ (LCOE)	0.04 ~ 0.12	0.1 ~ 0.28	0.02 ~ 0.11	0.05 ~ 0.12	(IRENA, 2018)
3	Social	**Job creation** Employee/MW	11	10	5	72	(Salman Ahmad, 2013)
4		**Social acceptance** Public opinion in favor of a technology	71%	80%	80%	55%	(IPCC, 2012)
5	Environment	**GHG emission** LCAs of GHG g-CO_2/KWh	81	217 - PV 89 - CSP	43	75	(Muhammad Amer, 2011)
6		**Land use** m^2/MWh	1.0	10 - PV 15 - CSP	10 (large dams)	500 (crops)	(Uwe Fritsche, 2017)
7	Technical	**Resource availability** Potential capacity MW	30000	50000	8000	NA	Author literature review
8		**Technology maturity**	Totally Matured	Matured	Matured	Developing	Expert opinions

4. 3 Hierarchical Structure Construction

Following up the first two steps in the proposed model the problem structure hierarchy shall be constructed in the third step to be as shown in *Figure* . The first step in the FAHP-based model is to determine the overall goal of the model which represents the top level of the hierarchy. The second level shows the main criteria for sustainable development, followed by the third level which represents sub-criteria, and finally different alternatives of renewable energy sources in Egypt.

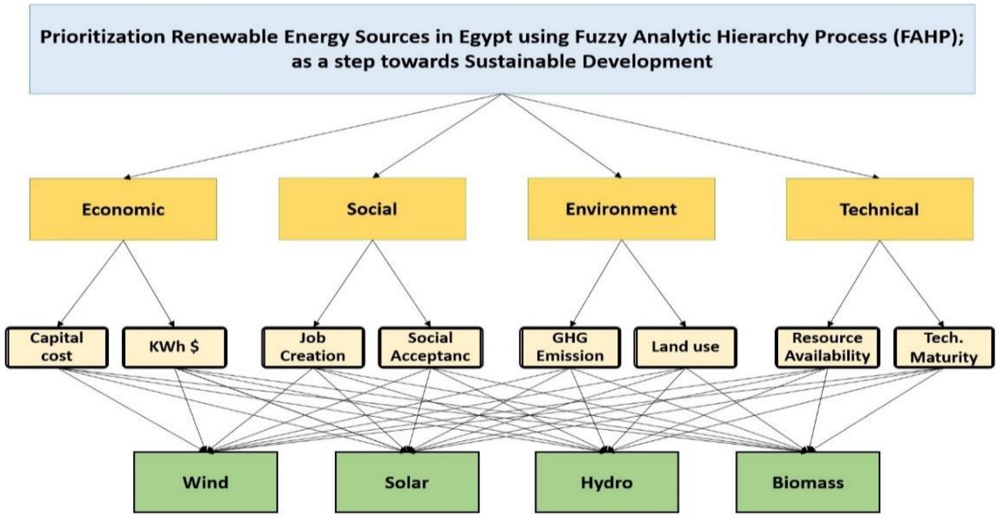


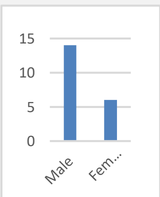
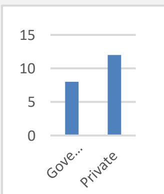
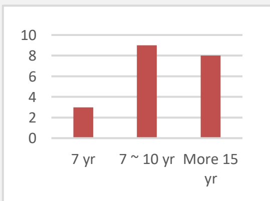
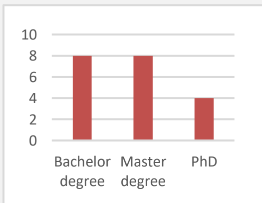
Figure 3 Hierarchical Structure Construction for FAHP model

4. 4 Decision-Making Subject-Matter Expert (SME)

In step number 4, it is crucial to construct the decision-makers' committee who will be responsible for the prioritization of renewable energy sources and the pairwise comparison process, in the case of a renewable energy field, we will contact a Subject-Matter Expert (SME) who is an experienced and authorized person specified in the renewable energy

Twenty SME selected from 36 experts participated, some result was ignored regarding inconsistency result below 0.1.

Table 5 Quality of the SME participants

Gender		Organization		Work experience			Qualifications		
Male	Female	Governm -ental	Private	7 years	7 ~ 15 years	More 15 years	Bachelor degree	Master degree	PhD
14	6	8	12	3	9	8	8	8	4
									

4. 5 Individual Judgment to FAHP Model

In step 5, a questionnaire survey was utilized to collect the necessary data required for analysis. This survey used the criteria and sub-criteria determined in previous discussions. The questionnaire consisted of three groups of tables, and the SEM are invited to rank and conduct a pair-wise comparison.

A computer program was created using the Visual Basic Editor of Microsoft Excel. The required input data will be entered using an Excel spreadsheet where the solution will be displayed as well. This software is provided by (Salaheldin, 2009),

4.5.1 Assigning Priorities to the Main Criteria

In this part, the questionnaire consists of 6 pair-wise comparisons for the four main four criteria's, with respect to the overall goal. Secondly, with respect to sustainable development criteria which sub-criteria better than the other. And finally a comparison between renewable energy sources with respect to sustainable development sub-criteria.

The questionnaire is designed where each decision-maker (DM) will express his/her own judgments to be reinterpreted as a pair-wise comparison.

Solving the problem. The previous procedures will be repeated for the responses of each of the 20 decision-makers from DM1 to DM20. For example, to solve the main sustainable criteria matrixes the result shown in *Table 6*.

Table 6 the results for DM's Judgments, for main criteria

	Economic	Social	Environment	Technical
	W1	**W2**	**W3**	**W4**
Total	36%	12%	14%	18%

Applying the group decision-making approach, the aggregations of the results for the DM's responses shall be done using the geometric mean for all values corresponding to each weight and then normalize. It is important to consider only the results with the acceptable values of inconsistency ratios ICR and ICR in both methods, the values of ICR below a certain value, here taken 0.1, are accepted.

If there are k decision-makers (DM1 to DMk), assuming all their responses have acceptable ICR values, the weight of the criterion from n criteria is calculated according to the following equations where the geometric mean is calculated in Equation 1, leading to nonnormalized weights and then normalized as Equation 2 to have the final weight.

$$W_{i(not\ normalized)} = \sqrt[\frac{1}{k}]{\prod_{m=1}^{k} w_{im}} \qquad m = 1,2 \dots, k \;\; i = 1,2 \dots, n$$

Equation 1

$$W_i = \frac{W_{i(not\ normalized)}}{\sum_{i=1}^{n} W_{i(not\ normalized)}} \quad i = 1,2, \dots, n$$

Equation 2

The final weights of the main criteria with respect to the goal are shown in figure 4

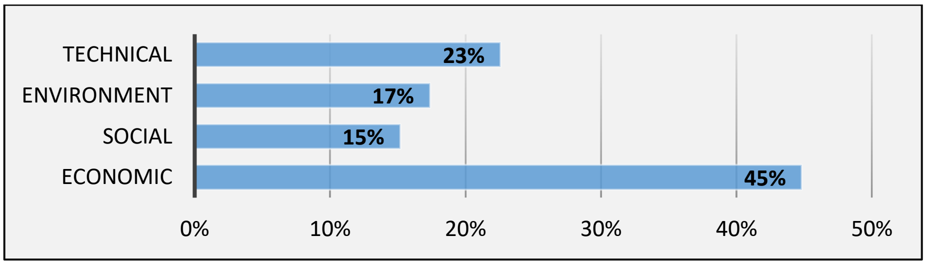


Figure 4 Aggregated Weights for the main criteria

4.5.2 Assigning Priorities to the Sub-Criteria

The "Survey – table two" consists of four separate questionnaires where each one represents the corresponding sub-criteria of the four main criteria. The first questionnaire includes two pair-wise comparisons for the two sub-criteria of the economic criteria, so that the weights Wa, Wb, corresponding to the sub-criteria capital cost and KWh price respectively, could be calculated. The same procedure could be done for the remaining sub-criteria.

Recalling the group decision-making approach, the final weights for sub-criteria with respect to sustainable development criteria by using the same method mentioned previously, after aggregation using equations (Equation 1), (Equation 2), the final Wight for sub-criteria are illustrated in final weight Figure.

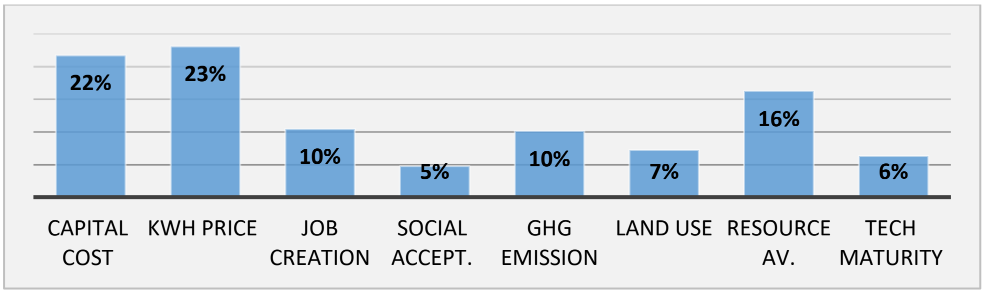


Figure 5 Aggregated Weights for the Sub-criteria

4.5.3 Assigning Priorities to the Alternatives

The final stage in step five for FAHP model is concerning the process of assigning weights for each renewable energy alternative. Again recalling the group decision-making approach, the final weights after aggregation are the following:

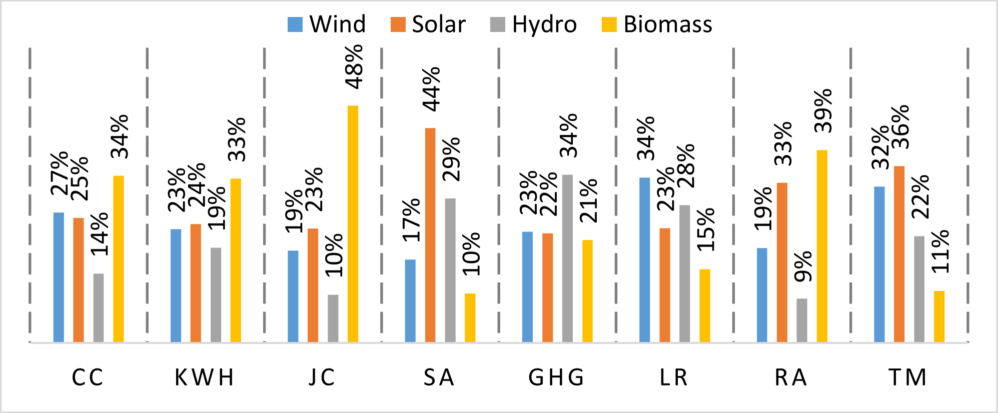


Figure 6 Aggregated Weights for the Alternatives With Respect to Sub-criteria

4. 6 Aggregation of Result

In this section, the final score for each of the renewable energy source alternatives will be calculated by integrating the results for each criterion of the main criteria and sub-criteria, the scores of each renewable energy source regarding each sub-criteria

The final evaluation is listed showing the final scores for the four renewable energy sources alternatives.

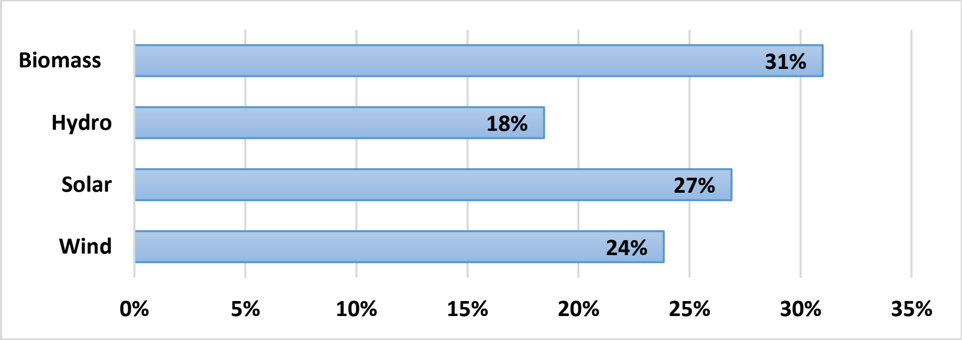


Figure 7 Final Result for Prioritization of Renewable Energy sources in Egypt final weight

5. Conclusion and Recommendation

5.1. Conclusion

The overall final result for prioritization energy sources in Egypt, which is the main research goal using the FAHP approach. Main sustainable development criteria and its sub-criteria were identified for the selection of the best alternative.

Biomass energy characterized by the high source potential which could improve energy security as well as create direct and indirect jobs and solves many related environmental problems such as recycling municipal, industrial and agricultural waste. Solar energy is ranked as the second most important source of clean energy in Egypt 27%, regarding the huge natural potential and the existing new ambitious projects. Wind energy ranked as the third important source 24% which can still play an important role in overcoming energy shortage problems. Finally comes the fourth renewable energy source hydro energy 18%, because Egypt already used around 80% from its direct hydro energy potential and the rest of the proposed projects depending on pumping storage power projects.

We cannot definitely say that a single renewable energy source is ideal for the whole country or for considering all sustainable development dimensions, however, the balanced diversity, and effective source management could offer a clear vision of achieving long-term sustainable development goals particularly in the national energy system.

5.2. Recommendations

The proposed FAHP model could be further applied in solving similar decision-making problems related to the energy field on the national or organizational level, such as prioritization and evaluation of energy efficiency policies or measures.

It is highly recommended to use the same model developed in the present work by an authorized governmental entity with high-level involvement of policymakers' individuals for the purpose of comparing the results with the current results acquired mainly from special matter experts. This could be considered in the future planning and policies development related to energy sources and particularly renewable energy.

It could be used for another country or even entity to similar decision-making problems.

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