A study on electrification of agricultural wells using fuzzy clustering algorithm and selection of optimal scenarios

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Every year a large amount of subsidized diesel fuel is delivered to farmers for irrigation purposes. In addition to low efficiency and high maintenance costs, diesel pumps increase environmental pollution and produce greenhouse gases. For this reason, in recent decades, the replacement of diesel pumps with electric pumps has been a priority for governments in most developing countries. Despite the many benefits of electrifying agricultural wells, providing the required demand for electric pumps has always been one of the main challenges facing grid operators. The development of renewable resources and distributed generation resources can be an effective strategy to provide economically justifiable solutions to supply the demand for agricultural wells and result in savings in fossil fuel consumption. Policymakers must have a clear understanding of different approaches regarding the electrification of irrigation systems and conceivable scenarios. In this paper, economic studies based on the enactments of the plan to supply electricity to Iran's agricultural wells are presented on a pilot scale. In this paper, a clustering of agricultural wells based on the fuzzy clustering method is presented. The purpose of using the fuzzy clustering method is to present the best classification of wells in terms of dispersion rate and select the best demand-supply scenario (of the four proposed scenarios) based on the analysis of the economic indices. In the final section of the paper, the analysis of the results of the proposed method is discussed.

keywords: *Irrigation Electrification, Fuzzy Clustering , Renewable resources.*

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1. INTRODUCTION

The use of renewable energy in different sectors of the industry has been the center of attention in the past decade. In this regard, many countries have moved towards using renewable energy in various sectors. Renewable energies are in essence free, environmentally friendly, and have a lower cost of operating and maintenance than their conventional counterparts. Through developing renewable energy resources, the fossil fuel used for providing energy for the agricultural sector can be put into other more valuable applications, resulting in a massive saving of fuels as well as an immense reduction in carbon production However, as it is with any technology, there are compromises, and renewable resources are not without their challenges. The high cost of construction, intermittencies, and dependence on climatic conditions are among their disadvantages. Consequently, it is essential for policymakers to have a clear understanding of different strategies regarding the electrification of irrigation systems and agricultural sectors and have a balanced view on the advantages, disadvantages, and economic implications of each scenario to promote renewable energy use and reduction of carbon emissions. This study aims to provide such perspective with regards to a variety of possible scenarios. One other method currently used in various sectors is distributed generation resources. Distributed generation resources can have the following advantages:

- Decentralization of large power plants and reduction of losses in distribution and transmission networks
- Reduce network peak load
- Reduce the need for investment in the development of production and transmission networks
- Possibility of using heat and CO_2 output in cases where the Combined Cooling ,Heat and Power (CCHP) unit is close to the load and improves suitability of power system

- Annual reduction of greenhouse gas emissions
- Ability to provide ancillary services to subscribers

However, distributed generation methods examined in this paper are mainly natural gas plants, which use fossil fuels, albeit cleaner versions, and therefore do not contribute to reducing CO_2 emissions as renewables. Thus, this is one of the most significant disadvantages of the distributed natural gas plants.

The agricultural sector is one of the critical sectors in this regard to replacing fossil fuels with electricity and fuel savings. Because of an increase in suitability, the ease of controllability via modem control and monitoring systems, and their lower noise emissions and maintenance requirements, switching to electric pumps for irrigation purposes can be incredibly beneficial to the farmers [1]. In the agricultural sector, irrigation and electric water pump are among the leading sources of electricity consumption. Depending on the depth of the agricultural well and the flow rate, the demand ranges from 10kw to 90 kW [2]. Therefore, supplying electricity to wells is exceptionally crucial, and electric pumps are among the most significant agricultural loads. There are over 2.1 million farms currently registered in the United States. According to [3], there is a potential for about 55,000 to 67,000 GWh of energy that is currently provided using fossil fuels on these farms, which is equivalent to $4.4 to $5.4 billion In potential new annual revenue in case of switching to electric methods. One of the main challenges in agriculture electrification is providing energy resources to replace the existing diesel pump with electric pumps. This issue is a major challenge, especially in places far from the network and for shallow wells. So, in addition to direct connection of electric pumps to the grid, the development of renewable resources and distributed generations have been adopted as one of the technological approaches to respond the demand in the agricultural field. With this approach, it is currently possible to provide electricity by using solar panels, wind turbine, distributed generation and finally as the last solution direct connection to the grid. Repayment to investors is calculated as a savings worksheet according to the tariffs set for each of the four solutions (according to the M&V order formulated in this plan) and repay to them in short-term periods. Choosing the optimal scenario for supplying electricity to agricultural wells requires carrying out feasibility studies according to the climatic conditions, agriculture wells characteristics for each area. So, it is necessary to choose the best solution among the 4 proposed methods for of different provinces of the country by taking into account the location, demand and average working hours of agricultural wells, etc. Authors in [4] have studied estimating the per capita demand for diesel in the agricultural sector. According to this study, the demand for diesel fuels is relatively inelastic due to the price change. Electricity, on the other hand, acts as a substitute input for diesel fuel. The study suggests that regarding the Iranian agricultural sector, the government policy on cutting energy subsidies is not enough for reducing diesel consumption and, therefore, non-price measures such as innovations in inter-fuel substitution technologies and applying efficient machinery are recommended to manage energy uses in agriculture.

Studies have been done on the benefits of using electro pumps for irrigation use in the agriculture sector compared to diesel-fueled engines. For example, in [5], authors have proposed methods for comparing the cost of using diesel pumps compared to electric pumps. In general, the suitability of electrical pumps range between 70 and 80 percent; In contrast, diesel pumps have approximately 30 to 40 percent suitability [6]. According to [7], in comparison with diesel pumps the electric pumps have two or three times more efficiency. Apart from reducing greenhouse gas emissions, electric pumps outperform fossil fuel-powered mechanical engines. Electric pumps, in general, perform better in power, torque, and fuel consumption compared to their fossil fuel-powered counterparts [8]. In Iran, in 2014, the Economic Council approved a plan aimed at reducing diesel consumption in agricultural wells. The project seeks to improve the environmental and economic situation across the country by replacing electricity (used by grid connection, solar energy, or Gas engine-generator) instead of diesel for pumping water from agricultural wells. By implementing this project, about 8.7 billion cubic meters of fuel are saved, and 0.7 million tons of carbon emissions are reduced. One of the main approaches emphasized in the plan is using renewable energy sources and distributed generation resources to supply energy for agricultural wells. Due to the variety of climates in different parts of the country, choosing the optimal solution for powering agricultural wells requires potential assessment and accurate technical and economic evaluation of each proposed method based on a comprehensive database. Many agricultural areas in Iran conventionally use fossil fuels, mainly diesel, for irrigation. The statistics of Iran's agricultural wells are summarized in Table 1. According to [8], there are 488 licensed wells, of which 244,000 wells have been electrified , and 229,000 wells have been given priority to electrify. Based on the regulations farmers are responsible for the costs of on-site electric devices such as electric pumps so these costs have been excluded from the final economic evaluation [9]. In line with the plans to reduce fuel consumption and supply electricity to agricultural wells, one solution is to provide the required energy with grid connection, solar energy, and distributed generation (Natural Gas CCHPs). Figure1 shows the overall scheme of the paper. The aim is to perform a feasibility study on the different methods of electrification of agricultural wells based on economic indices.

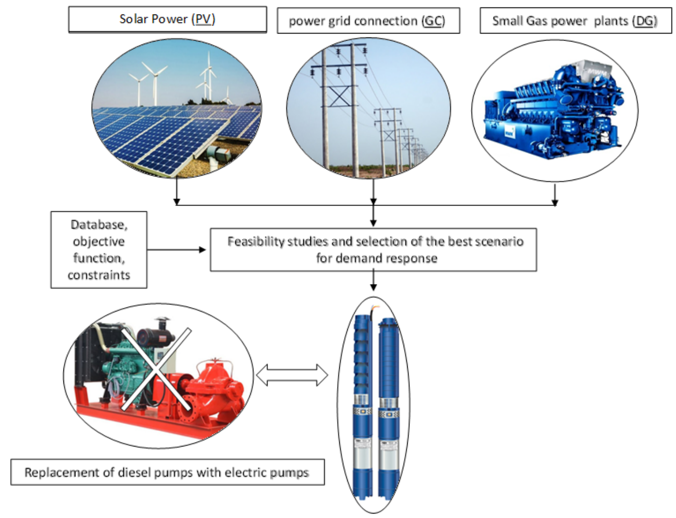

Fig. 1. The overall scheme of the proposed study

One of the main challenges in designing a plan to supply electricity to agricultural wells is to supply the demand for electric pumps using an optimal and economical solution, taking into account the indices for reliability and power quality. In most cases, agricultural wells are usually far from the mains grid, and supplying electricity to these wells requires considerable private investments. This problem and the others, such as increasing

Table 1. Reimbursement rate per liter of fuel saved [9]

Resource Type	GC	DG	PV&Wind
Reimbursement rate per liter of fuel saved (Cent/litter)	19	32	46

the load on the network, especially in areas where the electricity network has not been developed, such as rural areas, causes distribution companies to move toward using renewable energy and distributed generation to supply electricity to wells. To eliminate the adverse effects of connecting agricultural electric pumps to the power grid, the use of renewable energy sources and distributed generation can be the right solution. The advantages of using renewable energy and distributed generation in power supply to agricultural wells are numerous. However, using Renewable Energies can result in unique challenges. In order to reduce the effects of electric pump loads on the existing infostructure of power grid, use of renewable energy resources seem to be a preferable solution. By meeting the demand using the RESs and creating micro grids made of cluster of self-sustaining loads, the existing rid will not experience the negative effects of increasing the loads, and will benefit from lower line loss, and lower maintenance requirements. In some cases, the excess energy can be sold back to the grid, for example in the cases of CHPs. For example, agricultural electric pumps require an uninterrupted power supply for day-to-day (or 24-hour) operation, while solar generators can only be operated during the day. In order to solve this problem, either energy storage devices with very high energy capacity should be used, or the possibility of access and connection to the electrical grid in low generation conditions or the absence of solar radiation must be provided to supply the electricity required. The use of energy storage devices in large capacities results in a lack of economic justification. The ability to connect the solar power plant to the grid also requires the development of transmission lines and access to the grid. Therefore, considering the importance of economic issues in the planning stage and determining the appropriate solution for supplying electricity to agricultural wells, implementing any grid connection methods, solar and wind energy, or distributed generation sources requires feasibility studies for each one of the scenarios. This means, for example, that investing in the solar energy sector may not be economically justified in some places. One of the main challenges in the development of distributed generation generators is access to the gas network. Other factors such as environmental considerations, the topography of the region, and consideration involved in developing distribution lines are also essential and should be examined more closely. In this study based on the studies done by Renewable Energy and Energy Efficiency Organization (SATBA) [16] , the selected candidates for DG installation have been examined to have a natural gas network connections. There have been various case studies done on the problem of supplying electricity for agricultural use. Authors in [10] study the feasibility of solar-powered irrigation and discuss whether such a strategy could be implemented in Bangladesh. The study suggests that some of the crops can significantly benefit from solar power irrigation. In [11], the authors present the performance analysis of solar photovoltaic water pumping systems for irrigation and analyze the differences between the field performance data compared to the simulated results. There are various models proposed for solar pumps that are useful in irrigation schemes, and the solar pump has been identified as a good solution in certain isolated areas and cases, as is evident in [12] [13] [14] [15].As mentioned before, one of the main challenges in electricity supply is the clustering of wells, aiming to achieve the best power supply scenario required based on a predetermined index. The general structure of the problem of supplying electricity to agricultural wells is shown in Figure 1. The aim is to cluster agricultural wells (at the first step) and determine the best scenario for the supply of electricity to each cluster. The studies of the potential and benefits of using electricity in irrigation systems heavily lean toward conventional electrification methods, such as grid connection. In this study, the authors have examined the potentials of using renewables resources and distributed generation and conventional methods such as grid connection. After calculating the economic indices, this study suggests that using renewables can be an economically viable solution in the agriculture sector and demonstrates which of the four proposed scenarios of providing power is economically justifiable in what part of the studied area.

As far as the authors know, this is the first study to demonstrate and compare renewable methods with conventional electrifying irrigation systems. This paper presents a method for clustering of agricultural wells based on their dispersion rate and selecting the best possible scenarios to supply the required demand based on one of the solar powers, grid connection, and distributed generation sources.For this purpose, it is necessary to collect information on the coordinates of the wells, wells electricity demand, water flow, working hours (Per year), along with the suggested points for establishing distributed generation resources and renewable energy, should be collected. In this paper, at the first step, the objective is to find the best clustering of agricultural wells based on the extent of well dispersion (distance between wells) and distance to power generation sources. The next step is to find the best solution based on economic indices.

This way, after determining these indicators, decisions are made about the classification of wells, a different scenario for supplying electricity is suggested. In this way, economic indicators are examined for each of the scenarios, and the aspects of the matter are examined from the investor's point of view. At the end of the calculations, each cluster's cost and economic evaluation indicators are calculated for different scenarios, and the preferred solutions for each cluster based on selected index are determined.

2. METHODOLOGY

The electrification scenarios are Photo voltaic (PV), Distributed Generation Using gas fuelled CHP systems (or DG), Direct Grid Connection (GC) and Solar Pumps for fringe cases. In the cases of PV and DG, the clusters are imagined as microgrids, with connectivity to the upstream grid and bi-directional connections, which can support the demand by using the main grid as a backup for the costumers during low production hours.

A. Problem description and data collection

Due to the dispersion of agricultural wells and the dependence of potential wind and solar plants construction candidates on climatic conditions, determining the optimal scenarios for power supply to agricultural electric pumps requires a local feasibility study. In this paper, feasibility studies have been performed on a pilot list including 136 agricultural wells in the city of Sirjan, Kerman province. Conducting a feasibility study in the first step

Table 2. The Data used in the feasibility study

Numbers of Wells	Number of Proposed PV Sites	Number of Proposed DG Sites	The Demand Range of Wells	Objective Functions
136	47	80	4-172 kW	Net present value (Maximize)

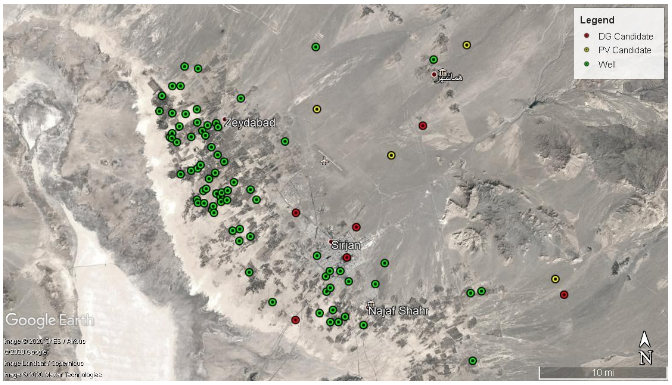

Fig. 2. Coordinates of Wells DG s and PVs in Kerman Province

requires creating a comprehensive database of field information needed to analyze scenarios, select the best scenario, and evaluate economic indices. The list of the required information is given in Table 2.

The information on the proposed solar and DG sites was extracted from a report on the identification of potential sites and the assessment of renewable energy resources by SATBA [16]. The gathered data and Coordinates were then unified in the same format, latitude, and longitude geographic coordinate system, and the results were cross-examined with multiple sources. The reasoning for the conversion is to import the data to the Google Map software and examine the location of the coordinates visually. For this purpose, two coordinate converters [17] [18] were used simultaneously, and the results were compared to be ensured.Fig.2 Shows the Coordinates of Wells DG s and PVs in Kerman Province.

Figure 3 shows the map of solar radiation on the Kerman province [19] and the position of the PV candidate sites purposed by SATBA. It can be seen that these sites correspond to the solar radiation maps, and the recommended points are in places with high solar energy potential.

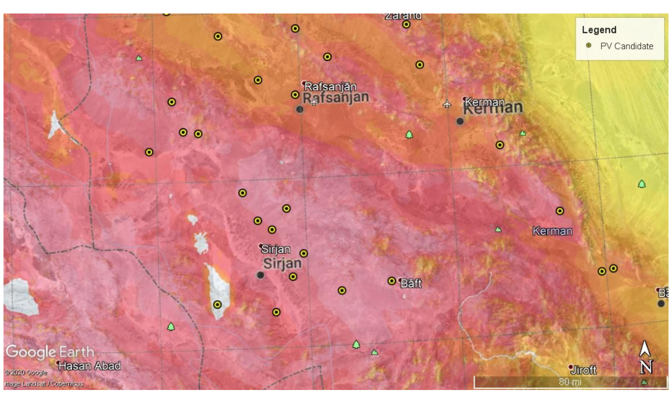

Fig. 3. The Solar Radiation in the Kerman Province [19]

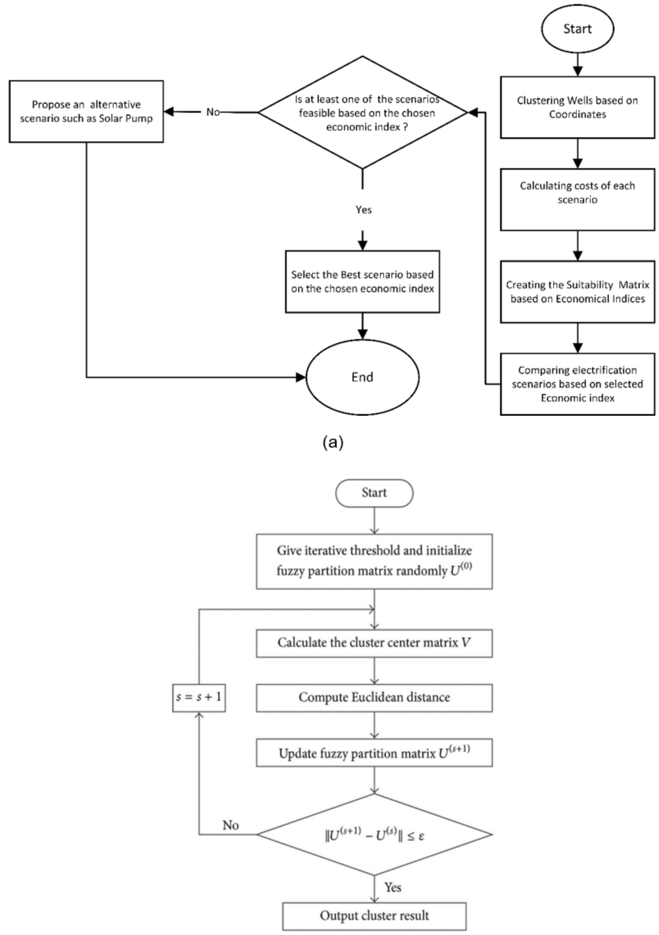

Fig. 4. Flow chart of the method (a) , flowchart of FCM method (b) [25]

B. Proposed Method

Figure 4 shows the flow chart of the proposed algorithm. After clustering the wells based on their coordination, the authors create a suitability matrix based on the economic indices of each cluster and each scenario. The row numbers of the suitability matrix are the cluster numbers. The matrix is divided into four different sections. Each section is associated with one electrification scenario: PV, DG, Grid connection, and Solar Pump. The economic indices of each scenario for each cluster are the arrays of the matrix. The structure of the suitability matrix can be seen in Figure 5. After the suitability matrix is calculated, the scenarios are compared based on their economic indices; an optimal scenario is proposed to the private investors. If a cluster does not have any feasible scenario based on economic indices, an alternative scenario of electrification via solar pump systems is proposed to the investors.

C. Clustering

It is not practical nor efficient to allocate a specific resource for each well. Therefore, it is necessary to cluster the wells and determine the suitable resource for each cluster. Clustering methods have long been used in various applications, one of which is clustering loads for optimal allocation of DGs and Renewable energy Plants. Clustering methods vary based on the application and their methods, but Common methods of clustering include the K-means clustering [20-22], Fuzzy Clustering [23-25],

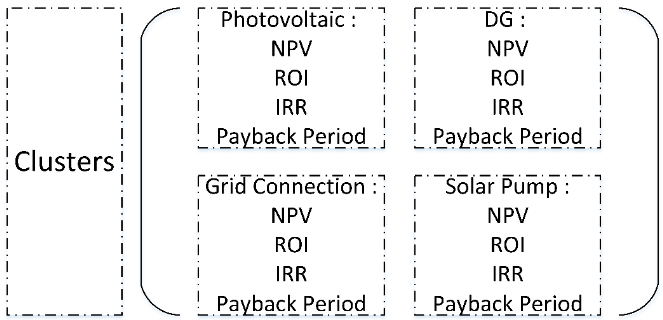

Fig. 5. The suitability Matrix

and density-based spatial clustering of applications with noise (DBSCAN) [26]. To calculate the optimized set of well and considering a group of well as a cluster of well, clustering methods for categorizing and sorting data are used. One of the most widely used clustering tools is FCM or Fuzzy clustering and has been used in allocation applications [23]. Fuzzy clustering is a clustering algorithm for dividing data into more than one cluster. This clustering method assigns a specific measure of similarity to each data, and the position of each data in each cluster is determined by comparing the measures of similarity. The steps of the fuzzy clustering algorithm are as follows:

- Determine the number of clusters in a data set.
- Random allocation of data to the relevant cluster.
- Repeat cluster algorithm to cover all data in closer clusters
- Calculate the cluster center of each cluster
- Identify the presence of any data in each cluster

After clustering, coordinates are given as a cluster center by the algorithm, which represents the centroid in that cluster. In this way, these centers can be used as a representative for the rest of the coordinates of the wells within the cluster. Choosing the optimum number of clusters is heavily dependent on the nature of data, and there are several methods to determine the number of clusters. However, for this project, after considering the number of wells and their distribution and consulting the local experts in the Kerman regional electric Co, and after several stages of trial and error, twenty-five clusters were deemed reasonable for this project. In order to ensure the proximity of the wells to the center of clusters, a constraint for the distance of the wells to the center of each cluster is considered so that the actual distance is not more than five kilometers. This number is based on empirical studies and appears to be acceptable for our study. Building power lines to supply wells beyond a 5 Km radius of clusters was deemed impractical. However, optimizing it with a numerical method is considered in our future endeavors. Once the clusters are identified, the wells inside the clusters and their coordinates are extracted. In Fig 6, it can be seen how 25 clusters are located among 136 wells. For more detailed view, the Figure 7 has been included

The following steps are used to determine the distance of the power plant to the clusters.
1. The closest power plant to the center of each cluster is identified
2. The distance of the closest well inside the cluster to the particular power plant is calculated.

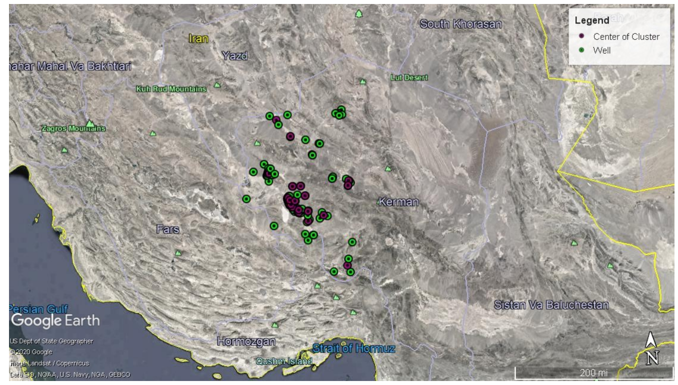

Fig. 6. Center of clusters and Wells in the Kerman Province

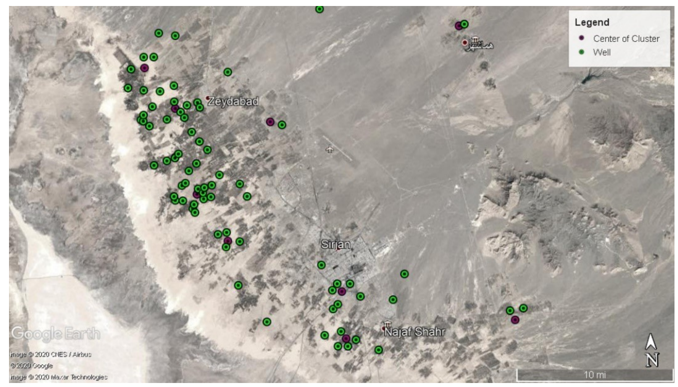

Fig. 7. Coordinates of the Center of Clusters and wells in Sirjan

3. The distance from the well to the power plant is the distance required for power lines to be constructed to be connected to the grid.
It is evident that for each cluster, only one power line is built from the power plant, and the rest of the wells will be electrified by connecting to the main feeder. It should be noted that in cases where there are overlaps between cluster radiuses, the priority is for the wells to be clustered with the closest center. Figure 8. shows the result of the clustering algorithm. Blue and Red dots, respectively, represent the Wells and the center of the clusters.

In order to calculate the distances between two coordinates in the latitude and longitude system, the following equations

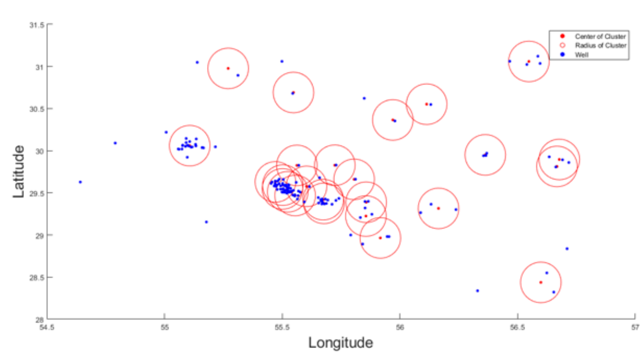

Fig. 8. The Coordinates of Clusters concerning the Wells.

called the 'haversine equations' have been used:

$$A = \sin^2(\frac{\Delta\varphi}{2}) + \cos\varphi \times \cos\varphi \times \sin^2(\frac{\Delta\lambda}{2}) \quad (1)$$

$$C = 2 \times \tan^{-1} 2 \times (\sqrt{A} \times \sqrt{1-A}) \quad (2)$$

$$D = R \times C \quad (3)$$

Where φ is latitude and $\Delta\varphi$ is the difference in latitude, λ and $\Delta\lambda$ are the longitude and the difference in longitude, and R is the radius of the earth equal to 6371 km. D is the final distance while C and A are the parameters calculated using the latitude and longitudes.

3. RESULTS

The simulation results for scenario 136 of Kerman sample wells, taking into account the costs mentioned in the previous section, are acquired. Three economic indices have been used to demonstrate the results: The economic Indices used are:

- Net present value: The net present value represents the difference between the value of the input cash flow and the current cash outflow.
- Internal rate of return: The internal rate of return represents the average annual profit of a project.
- Payback Period: The payback period is a period in which the cost of investment equals the amount of profit.

In general, the costs are divided into three sections:

- Costs related to delivering power lines from each energy center to each cluster and the closest well
- Transformer costs are obtained using KVA information for each well, assuming a power factor of 0.8.
- • The cost of the power lines inside each cluster obtained by the algorithm. It follows the same rule of $ 10,000 per kilometer.
- Well equipment

In total, for four scenarios of power supply with a solar power plant, power supply using DG power supply connection to the network, and power supply through a solar pump, the result of the research is as follows. There are 136 wells and 25 clusters for the scenario of the solar power plant and considering the 47 candidates proposed by SATBA. The results are as follows:

The NA symbol means that cases do not have an acceptable answer. Therefore, it can be seen that out of 25 clusters, twelve clusters have acceptable economic Indices for the PV scenario. These scenarios have different economic Indices and should be compared with other scenarios for decision-making. In this scenario, twenty-five clusters of well consisting of 136 Wells have been electrified using 80 potential sites proposed by SATBA. A summary of the results of calculations of economic indicators for the supply of demand based on the DG solution is presented in Table 4. It can be seen that in this scenario, out of twenty-five clusters, twelve clusters have acceptable economic Indices, and the use of the DG method is feasible. In the table, the NA symbol means that the scenario in these cases does not have an acceptable answer. In this scenario, the power for wells and clusters is supplied through the network connection. In this case, for 136 wells, the distance from the center of the clusters to the closest

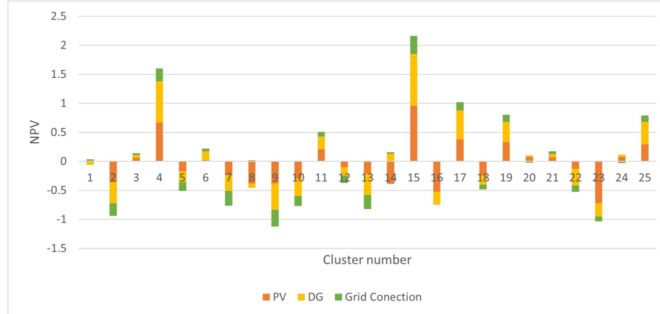

Fig. 9. The Coordinates of Clusters concerning the Wells.

place connected to the network, i.e., places such as main roads or networks connected to the network, has been calculated. An essential issue with network connection scenarios is deciding whether or not to cover the hidden costs of generating electricity. From the investor's point of view, the cost of electricity consumption is estimated at $ 0.0008. This cost, however, for the operator includes the following costs: The operator's responsibility is to decide whether to pay for these costs or make the Private investor pay for them. In this scenario, assuming the cost of electricity at $ 0.0008, the NPVs of the network connection scenario from the investor's point of view is:

It can be seen that in this scenario of 25 clusters, it is economically justifiable for 13 of the clusters to use the grid connection scenario. The NA symbol means that the scenario in these cases does not have an acceptable answer. The overall NPV between the three different scenarios is manifested in Figure 9.

A. Solar pump

In this scenario, comparing the NPV index for all previous scenarios, clusters that were not justified in any of the introduced scenarios are considered an investment package. In this scenario, each well is powered by a solar pump. These calculations are the same as in the case of the PV Except, in this case, the power line and transformer cost are eliminated. For Comparison, the NPV between the four Scenarios is as follows:

It is observed that for ten clusters, none of the above scenarios are justified, so these clusters are chosen as candidates for the Solar pump. The feasibility of the Solar Pump option as an alternative electrification plan was done. The study was done on all of the wells chosen for the solar pump as a single investment package with the assumption that the private sector would examine the feasibility of electrification of these wells in a single investment. The similar study show that using the battery energy storage for agricultural purposes is very expensive and requires high initial investments, however use of water banks for irrigation in times of peak demand and high grid congestion can be attractive. In Table 7, all remaining clusters are assumed to be combined as one cluster, and economic calculations are performed for this cluster.

4. CONCLUSION

In this paper, the electrification plan for diesel pumps and irrigation systems is studied. After gathering required data for possible candidates and their capacity and coordinates, a Fuzzy clustering algorithm is used on wells to cluster them into candidates for electrification with different power plants. Four Different scenarios, i.e., PV, DG, Grid connection, and solar pump, were examined. In this paper, the fuzzy clustering method is

Table 3. The economic indices of PV electrification scenario

Cluster Number	Total investment cost (million dollars)	NPV	IRR	Payback Period (Year)
1	0.349105817	-0.011447432	0.139962247	8
2	0.54352598	-0.355065486	-0.096042885	NA
3	0.229672872	0.062833519	0.229446376	5
4	0.770133244	0.672767411	0.387048861	3
5	0.240754415	-0.170081729	-0.125046043	NA
6	0.394453024	0.017804306	0.163609728	7.5
7	0.35281281	-0.238951262	-0.108772395	NA
8	0.730528683	-0.383054647	-0.03525453	NA
9	0.454240966	-0.37964202	-0.213588593	NA
10	0.348608175	-0.297566791	-0.229182153	NA
11	0.377820599	0.209155314	0.305075572	4
12	0.259055435	-0.102005023	0.017600293	NA
13	0.348837972	-0.219271383	-0.083495616	NA
14	0.822598521	-0.384820499	-0.011535931	NA
15	0.962515117	0.961352424	0.418211283	3
16	0.613858961	-0.523554974	-0.228550672	NA
17	0.566429837	0.381762022	0.33637266	4
18	0.391566973	-0.246295342	-0.083706221	NA
19	0.513294136	0.332814956	0.329771503	4
20	0.221804119	0.077573227	0.250479044	5
21	0.421058756	0.07168691	0.200233705	6
22	0.344216388	-0.130235203	0.023428815	NA
23	0.730023332	-0.722170811	NA	NA
24	0.279939236	0.07931358	0.232160055	5
25	0.543024887	0.293268554	0.301521383	4

Table 4. The economic indices of DG scenario

Cluster Number	Total investment cost (million dollars)	NPV	IRR	Payback Period (Year)
1	0.300444179	-0.046978503	0.100821095	NA
2	0.508290584	-0.366821369	-0.13393789	NA
3	0.174579957	0.044992054	0.225015017	5.5
4	0.377412956	0.705710719	0.626487353	2
5	0.240204096	-0.18715314	-0.170621436	NA
6	0.154454987	0.15500892	0.419396062	3
7	0.356230932	-0.270759948	-0.157826403	NA
8	0.331218045	-0.070384181	0.082236475	NA
9	0.508450617	-0.452452386	-0.265640704	NA
10	0.335518327	-0.297203748	-0.261168537	NA
11	0.222183786	0.218433872	0.414334919	3
12	0.262876742	-0.144985729	-0.047205864	NA
13	0.456834796	-0.35957471	-0.176174443	NA
14	0.197059078	0.131562119	0.33473658	3.5
15	0.552392782	0.891772118	0.566548223	2
16	0.292098498	-0.224311166	-0.163016481	NA
17	0.216170379	0.495596607	0.724368572	1.5
18	0.260150447	-0.151101261	-0.060545672	NA
19	0.28800394	0.347133888	0.468758681	3
20	0.196290373	0.028439369	0.192926843	6.5
21	0.313750375	0.056132676	0.202713632	6
22	0.443194299	-0.282567795	-0.088008037	NA
23	0.229443098	-0.223548547	-0.415702601	NA
24	0.233992651	0.035683039	0.195125237	6.5
25	0.241475441	0.3862942	0.563087091	2

Table 5. Operating costs [27]

Type of Cost	Unit Price
Total Cost of power generation on the power grid (kwh / $)	0.1
Power plant construction cost (kW / $)	1000
Power Plant Repair Costs (kW / $)	8
Power outage (kwh / $)	1.5

used to classify agricultural wells (electro pumps) and determine the best electrification scenario. The economic indices for each scenario were shown and compared. Then, the clusters were assigned to the best suitable electrification plan. It was shown that not all scenarios are economically viable for electrification, and the economic indices guide investors to approach the problem based on their best financial interest. It was also manifested that in some scenarios, none of the conventional methods of electrification, such as grid connection and PV and DG, are economically justifiable; therefore, more novel methods such as Solar pumps were introduced to solve this problem. Future works concerns optimizing the clustering method, number of clusters as well as using other methods for evaluating the economic indices are also considered and will be presented in future papers.

5. DATA AVAILABILITY STATEMENT

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

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Table 6. The economic indices for the Grid connection scenario

Cluster Number	Total investment cost (million dollars)	NPV	IRR	Payback Period (Year)
1	0.0296379	0.0338377	0.4532909	3
2	0.2497994	-0.2143712	-0.2334109	NA
3	0.0229922	0.0319954	0.5136144	2.5
4	0.0453378	0.2259098	1.331731	< 1
5	0.1625985	-0.1493129	-0.3008919	NA
6	0.0265572	0.0509421	0.6377541	2
7	0.2756077	-0.2542031	-0.3066159	NA
8	0.0430957	0.0222251	0.295098	4
9	0.3050584	-0.2910347	-0.3617419	NA
10	0.181149	-0.1715539	-0.3475175	NA
11	0.0317978	0.0785464	0.7651178	1.5
12	0.1554143	-0.1258908	-0.1929918	NA
13	0.2675263	-0.2431693	-0.288439	NA
14	0.0545766	0.0277203	0.2930344	4.5
15	0.0535454	0.308118	1.5042129	< 1
16	0.0160351	0.0009409	0.1676494	7.5
17	0.0332942	0.1449542	1.1908198	< 1
18	0.1098133	-0.0825041	-0.1521733	NA
19	0.0333425	0.1257156	1.0598001	< 1
20	0.078531	-0.0222518	0.057909	NA
21	0.0469363	0.0456938	0.4119581	3
22	0.1536913	-0.1134655	-0.1439858	NA
23	0.0878785	-0.0864023	-0.4511991	NA
24	0.0936035	-0.0260684	0.0596095	NA
25	0.044469	0.1127439	0.7800279	1

Table 7. Possible Solar Pump candidates based on NPV comparison

Cluster Number	PV	DG	Grid Connection	Solar Pump
1	-0.011447432	-0.0469785	0.033837708	
2	-0.355065486	-0.36682137	-0.21437116	Possible candidate
3	0.062833519	0.044992054	0.031995383	
4	0.672767411	0.705710719	0.22590976	
5	-0.170081729	-0.18715314	-0.149312917	Possible candidate
6	0.017804306	0.15500892	0.050942144	
7	-0.238951262	-0.27075995	-0.254203133	Possible candidate
8	-0.383054647	-0.07038418	0.022225133	
9	-0.37964202	-0.45245239	-0.291034673	Possible candidate
10	-0.297566791	-0.29720375	-0.171553892	Possible candidate
11	0.209155314	0.218433872	0.07854643	
12	-0.102005023	-0.14498573	-0.125890795	Possible candidate
13	-0.219271383	-0.35957471	-0.243169339	Possible candidate
14	-0.384820499	0.131562119	0.027720318	
15	0.961352424	0.891772118	0.308117963	
16	-0.523554974	-0.22431117	0.000940948	
17	0.381762022	0.495596607	0.144954161	
18	-0.246295342	-0.15110126	-0.082504059	Possible candidate
19	0.332814956	0.347133888	0.125715585	
20	0.077573227	0.028439369	-0.022251781	
21	0.07168691	0.056132676	0.045693795	
22	-0.130235203	-0.28256779	-0.113465465	Possible candidate
23	-0.722170811	-0.22354855	-0.086402328	Possible candidate
24	0.07931358	0.035683039	-0.02606836	
25	0.293268554	0.3862942	0.112743917	

Table 8. The economic indices for the Solar pump

Total investment cost (million dollars)	0.455290859
Total Income from investment per year (million dollars)	0.265253495
NPV	0.697066535
IRR	0.546828511
Payback Period (Years)	2

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