Management of Renewable Energy Production and Distribution Planning Using Agent-Based Modelling

Mohammed, N. & Al Bazi, A.

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Agent-Based Modelling

Nooriya A.Mohammed[1,2], **Ammar Al-Bazi**[3]
[1]Institute of Economics, University of Erlangen-Nuremberg, Germany
[2]Planning and Studies Office, Ministry of Electricity, Baghdad, IRAQ, nooria.abed@gmail.com
[3]School of Mechanical, Aerospace and Automotive Engineering, Coventry University, UK

Abstract: The use of renewable energy sources is increasing worldwide to achieve energy production sustainability. To reach this goal and mitigate against climate changes all energy resources must be optimally managed. In this paper, an innovative multi agent-based heuristic optimisation system is developed to address renewable energy systems' challenges associated with the management of renewables including storage devices, planning of energy distribution, and consumption flexibility. A new heuristic algorithm is developed to introduce an efficient and sustainable storage strategy of surplus energy generated by different renewable resource options. This leads to archiving optimised storage levels of energy across different located storage devices in order to face risk of production shortages due to weather conditions. In order to test the behaviour of the developed system and address its benefits, a case study in the Republic of IRAQ is developed. Twelve major cities (in order of population size) distributed in 5 main regions including North, South, East, West and Middle parts of the country are selected, and hybrid renewable power generation sources such as Wind, PV-solar and Hydro are implemented based on weather changes. The results highlight the effect of high suppliers' rate on electricity exchange and production planning from differently used renewable technologies. A sensitivity analysis is conducted to verify the behaviour of the developed model on different demand behaviour types.

Keywords: Renewable energy sources; Energy production management; Storage devices; Energy distribution planning; Agent-based modelling; Heuristics optimisation

1. Introduction

In recent years, the worldwide trend of introducing renewable energy sources is increasing and moving towards achieving sustainability in order to protect the environment. Pathways towards a 100% renewable energy (RE) power sector are also explored [1]. This is a huge challenge, as countries contribute to the increase of climate change and need to limit the use of fossil fuels. In addition, the effective use and management of renewable energy sources as well as the distribution and planning of energy generation have several challenges. One of these challenges is how renewable energy suppliers could manage their intermittent sources based on weather changes for efficient energy generation. This type of challenge becomes even more complex since weather changes continuously over time. For example, during a day, the weather could change from sunny to partial cloudy to rainy and then sunny etc. Other challenges are related to how to efficiently respond to different consumer demand types including households, industry, government and tourism under uncertain weather conditions. In addition, the uncertainty of energy supply has amplified as a result of increasing the adoption of intermittent renewable energy sources. Thus, to satisfy the demand at high reliability and sustainability levels, managing the charging process of differently located storage devices to take advantage of surplus generated energy could be one of the solutions. Managing the energy exchange between different regions could be a rescue option in case a shortage of energy occurs. Therefore, energy production and distribution between all the renewable energy system components including suppliers, distributors and consumers needs to be managed in an optimal way to achieve the best energy planning and distribution practices of such renewable energy systems. Taking both

A comprehensive review of the management of energy suppliers including production from different renewable energy sources was investigated by a number of researchers including but not limited to Bussar et al. [2] who confirmed that the flexibility of adopting various renewable energy sources is required to provide standard security of energy supply by the match between demand and supply at any given time. Mengova [3] explored the determinants of energy production from renewable sources and analysed the major constraints faced in moving towards a more environmentally friendly generation and use of energy. In 2019, authors in [4] presented a fast and accurate Real-Time Optimization (RTO) technique to manage production of different types of renewable energy sources (RES), and a design methodology for a hybrid energy system based on multiple renewable power sources was presented [5], and a power generation planning model that considers a high penetration of a wide range of renewable energy sources was developed [6]. A new analysis algorithm for determining the amount of renewable energy required in a wide-area transmission network was developed in [7], and a micro-grid model that integrates the power plants driven by renewable energy sources employing a photovoltaic system for optimisation of utilisation of local renewable energy for on-grid area was proposed [8], and a multi-agent system for coordinating and controlling the renewable energy power generation and consumption units was implemented [9].

The role of energy storage devices for the integration of renewable energy sources in future power systems was studied [10], and a new cost-based optimisation strategy for optimal placement, sizing and control of distributed energy storages was developed [11]. Imperialist Competitive Algorithm (ICA), a meta-heuristic optimization algorithm was proposed to determine optimal energy management with renewable energy sources, battery energy storage and load control [12]. A multi-objective, bi-level optimisation model for cooperative planning between renewable energy sources and energy storage units in active energy distribution systems was proposed [13], and the financial benefits of distributed energy storage systems that are integrated into conventional electric grids was investigated [14]. An optimal placement methodology to solve a complex optimisation problem of energy storage in the presence of a renewable distributed generation was presented, and storage sizing was modelled [15]. In Atzeni et al. [16], a general grid model to provide the optimal production and/or storage strategies was developed, and the effects of wind power generation on the short-term operation of the electricity system were generated [17]. The authors in [18] investigated the problem of power balancing in a renewable-integrated power grid with storage and flexible loads, and capacity requirements of electric power generation and storage, involving conventional and renewable sources were estimated [19]. An intelligent control strategy for photovoltaic (PV), and a multi-battery bank connected to the grid was developed to ensure load sharing based on the source capacity among sources [20].

The context of distribution planning of energy networks by taking into account the uncertain behaviour of the renewable energy production and consumer has also been investigated. The drive to make traditional distribution networks change into active distribution systems, and why the traditional deterministic planning methods have become unsuitable under the high penetration of renewable energy was also discussed [21]. Da Fonseca Santos [22] discussed the inherent uncertainty and variability of renewable energy systems along with their integration with other smart grid enabling technologies. A scenario-based dynamic economic dispatch model for periodically implementing its resources on successive days with uncertain wind speed and load power distribution system that is suitable for plug-and-play of distributed renewable energy and distributed energy storage devices was developed [25]. Kayal and Chanda [26] proposed an efficient approach for optimal placement and sizing of solar and wind DGs in a distribution territory. Faia et al. [27] used the photovoltaic generation, available storage capacity, and the flexibility of loads to find the optimal scheduling of energy for a residential house energy requirement. Ghiani et al. [28] presented the planning actions for the transition of the current passive distribution system towards a smart local energy community. An integrated energy distribution planning approach, combining a large share of variable renewable energy sources into the energy distribution system without using storage devices has been discussed [29]. A novel techno-economic optimisation method for proper location and size selection of multiple solar and wind generation units in distribution network was proposed [30]. Zhang et al. [31] proposed an innovative co-planning model of wind farm, energy storage and transmission network. The best management of energy storage devices in a distribution system considering forecast uncertainties in day ahead operation was achieved [32], and the evolution of the planning tools of the future active distribution systems, highlighting the main points of improvement against the traditional planning procedures was discussed [33]. Jafari et al. [34] used an off-line dynamic programming-based optimisation model and a real-time rule-based controller to optimally control the power flow in the system. Mastrocinque et al. [35] developed a multi-criteria decision-making framework for sustainable supply chain development in the renewable energy sector. The optimal power generation and load management problems in off-grid hybrid electric systems was addressed [36], and a novel stochastic energy and reserve scheduling method for a microgrid which considers various type of demand response programs was proposed [37]. Zamani et al. [38] proposed a probabilistic model using a modified scenario-based decision-making method for optimal day ahead scheduling of electrical and thermal energy resources in a Virtual Power Plant (VPP).

From the above studies, it can be concluded that there are only a few studies considering both energy production management of renewable energy sources combined with distribution planning of energy to satisfy different consumers requirements. However, the effect of other suppliers' production key features including management of energy levels in different locations' storage devices, the effects of weather changes, and energy exchanging facility between different combined regions have not previously been addressed and that is the aim of this work.

Therefore, the main aim of this paper is to develop an innovative multi agent-based optimisation system for managing renewable energy sources and achieving best distribution planning of energy to satisfying different consumers' demands. This takes into account weather conditions and possible scenarios for energy storage using differently located storage devices.

The main contributions of this study compared to other studies in the area of the management of renewable energy production and distribution planning can be summarised as follows:

(1) proposing a multi agent-based heuristic optimisation system that considers both renewable energy production management and distribution planning for different consumers' demands.

distribution planners and managers working in the energy sector to achieve the most efficient production and distribution plans for energy by achieving the best utilisation of the renewable energy resources including storage devices.

(3) Best handling of different energy consumption behaviours, achieving optimal utilisations of differently located storage devices, reduction of shortages, best exchange rates of energy between different regions and subsequently the best satisfaction of consumers' requirements.

The rest of the paper is organised as follows: in Section 2, development of an innovative multi agent-based optimisation system including a new heuristics algorithm of controlling storage operation of energy at differently located storage devices is presented. In Section 3, demand analysis and results discussion are discussed. In section 4, a sensitivity analysis is presented followed by the conclusion and future work in the final section.

2. Research Methodology

2.1 The Multi Agents Representation of the Renewable Energy Distribution Network

The proposed multi agent-based optimization model involves a number of competitive agents including Suppliers (agent) that have different types/numbers of K Sources (sub-agent). The second agent is comprised of Distributors, which involves a number of different L distribution companies that are used to transmit energy from selected supplier(s) to consumers. The third agent is the regional demand (agent), in which each region consists of different cities that each have different demand/consumer types (sub agent). However, a socio-technical system including behaviour of consumers and suppliers was developed using the agent-based modelling approach [39]. See Figure 1 for the renewable energy distribution network agents.

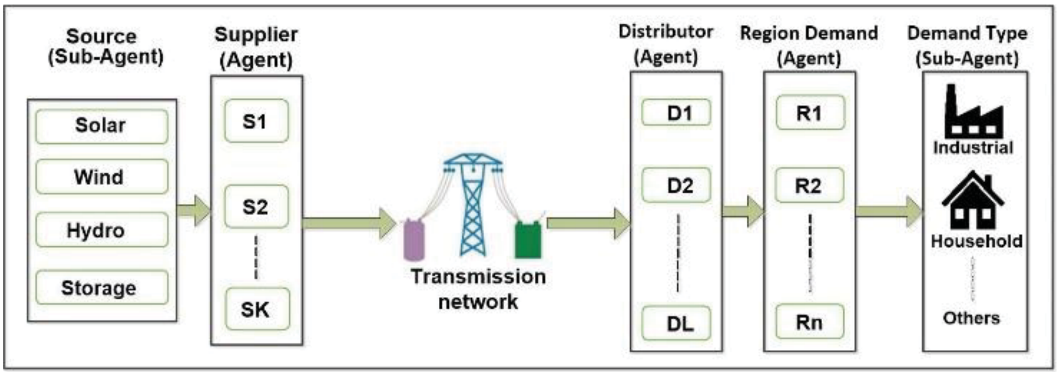

Figure 1 Multi-agents of the renewable energy distribution network

In Figure 1, each supplier has a set of rules which govern its interaction/collaboration with a distributor agent. The distributor agent also has rules when interacting with different regions and demand agents including its sub-agents. The rules of the supplier agents are based on a function of their output power and energy storage capacity which is very expensive. These rules help the supplier to decide the boundaries of its maximum power capacity of energy storage. In order to design a sustainable energy supply, several supplier-distributor selection rules (including internal and external factors) must be considered. These rules are a sample of Supplier-Distributor selection rules.

Table 1. Supplier-Distributor selection rules

Collaborated Agents	Rules
Supplier ⇨ Distributor	• Suppliers may bid strategically above their marginal cost. • Each supplier aimed at the fulfilment of the target production with resource constraints. • So-called block bids can be proposed, conditional bids are submitted for several hours. • Negative bids are also possible. • Spot market quantities are traded completely dependently or independently of its location.

Other common rules for the Distributor-Consumer agents are identified. These rules could be used to determine how a sub-agent for household consumer types will behave under a specific set of attributes. Then, some members of each group could make decisions based on adopting one rule from these different offers of distributors, e.g. in the household some consumers prefer the fixed tariff and some others the variable tariff. The rule might specify with a probability value assumption for each sub agent that adopted this rule and then compute the relative influence of these factors on the total demand.

2.2 The Proposed Message-Sequence Model of the Renewable Energy Distribution Network

The purpose of developing this message-sequence model is to represent the interactive ability of individual agents of the renewable energy distribution network including suppliers, distributors and consumers including their sub-agents represented by renewable energy technology, distribution companies and different consumer requirements' types respectively (see Figure 2).

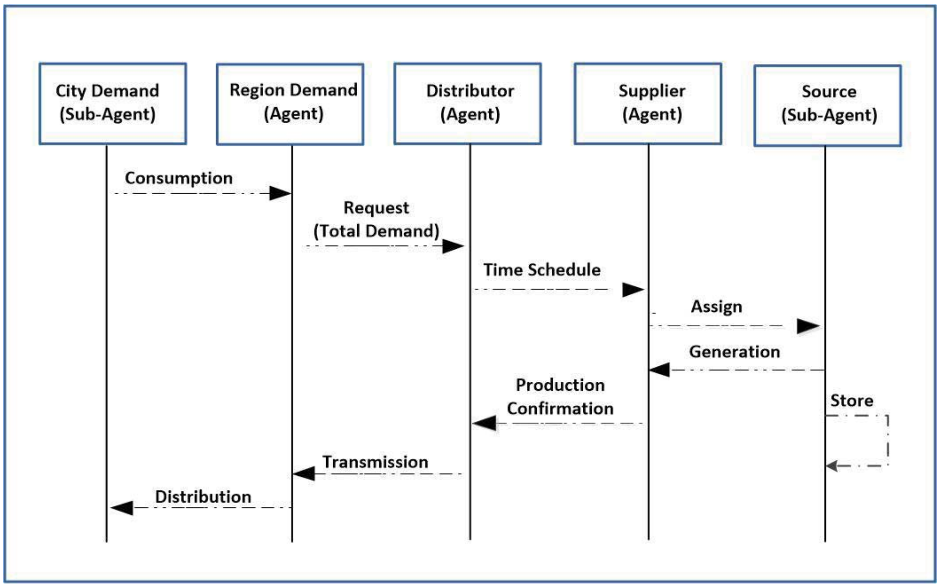

Figure 2. Message-Sequence Model for the renewable energy distribution network

supplier (agent) providing the required demand volume and the time schedule of that demand. The suppliers will utilize their renewable energy sources (sub-agent) to estimate the energy generation, considering at some extent weather conditions, and message back to the distributors with their actual generation capacity. Energy storage and retrieval from/to storage devices is also considered to store surplus energy and to support the city/region demand. The supplier will then pass on a notification confirming the availability of the requested energy volume within the requested time frame. The distributors will then transmit the energy via their grid networks to the region demand agent, which will in turn distribute this energy among different cities at each region.

2.3 The Proposed Heuristics Algorithm

In order to achieve the best planning of energy distribution across the different network components, a heuristics optimization algorithm is proposed. Figure 3 shows the architecture of the multi agent-based heuristics optimization model of the renewable energy distribution network.

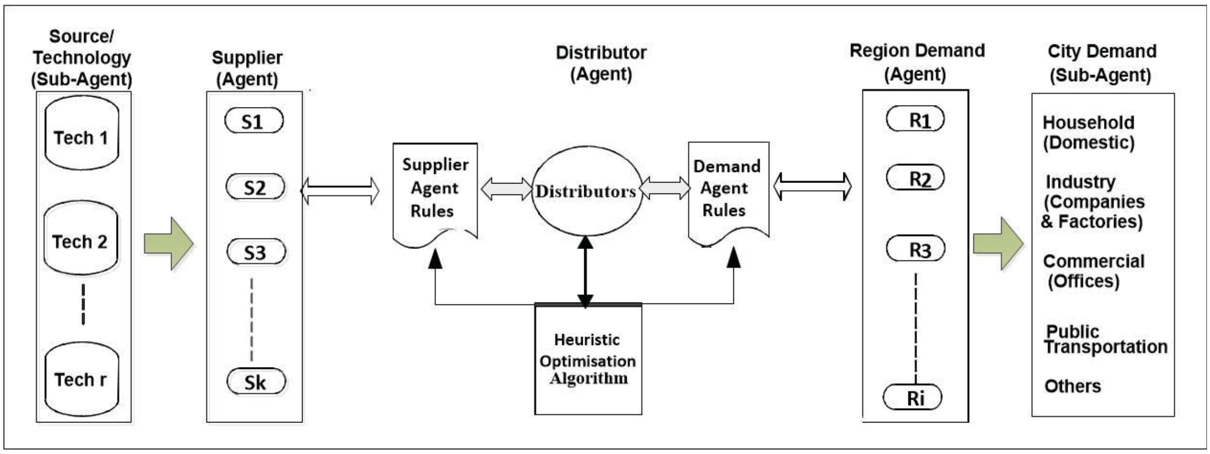

Figure 3. Architecture of the multi agent-based heuristics optimisation system

This algorithm is developed to assure the best consumer demand satisfaction of energy. This is achieved by identifying both the surplus and shortage quantities of energy per region and decide which differently located storage devices will be selected to accommodate the surplus energy. In case a region suffers from a shortage of energy, other regions could help in providing energy to the region on shortage. In general, the proposed algorithm works toward achieving a gradual and sustainable storage of energy across differently located storage devices, in order to face any generation disruption contingencies.

Notation

t: Time in hour (t=1,..,24)
i: Consumer type (i=1,…,m)
j: City j (j=1,…,n)
k: Region k (k=1,…,3)
l: Distributor number (l=1,..,a);
r: Supplier number (r=1,..,b);
S: Source/technology number (t=1,..,S);
h: storage device number (h=1,..,H)

C_{ijkt}: Consumption per consumer type *i*, city *j*, region 1 at time *t*
DI_{lk}: Distributor *l* for region *k*
DIS_{lkt}: Distribution Volume by distributor *l* for region *k* at time *t*
TP_{kt}: Total Energy Production per region *k* at time *t*
TP_{rskt}: Energy Production by supplier *r* using source/technology *s* per region *k* at time *t*
TP_{lkt}: Total Energy Produced by Supplier *l* per region *k* at time *t*
SU_{kt}: Surplus per region *k* at time *t*
SD_{hrk} : Storage device *h* available at supplier *r*, region *k*
RSC_k: Region *k* Storage Capacity
SC_{Max}: Maximum Storage Capacity
SH_{kt}: Shortage (unsatisfied demand) per region *k* at time *t*
EE_{kkt}: Energy Exchange between regions *k*; *k≠k* at time *t*

The Heuristics Algorithm Steps

```
Run the System
Define $SC_{Max}$
Set time t = 1 (in hour)
Define $C_{ijkt}$
Calculate $C_{kt} = \sum_{i=1}^{m} C_{ijkt}$ , j=1,..,n ; k=1,..,3
Estimate $DIS_{lkt}$ provided by each distributor $DI_{lk}$ using equation (1), l=1,..,a ; k=1,..,3
Calculate $TP_{kt} = \sum_{r=1}^{b} TP_{rskt}$ , s=1,..,S ; k=1,..,3
Update Total Production $TP_{kt}$ and Energy Surplus $SU_{kt}$ , do
For energy surplus do,
IF $TP_{kt} \geq C_{kt}$ THEN
Set $\sum_{l=1}^{a} DIS_{lkt} = C_{kt}$ ; set $C_{kt} = 0$
        Update $TP_{kt} = TP_{kt} - C_{kt}$
        Calculate $SU_{kt} = SU_{kt} + TP_{kt} - C_{kt}$
For energy charge strategy do,
Select $SD_{hrk}$ with the least energy level and charge it until it gets same level of
        charging of $SD_{h+1rk}$;
IF same levels two storage devices $SD_{hrk}$ , $SD_{h+1rk}$ , do select randomly for charging
Charge $RSC_k$ level by $RSC_k = RSC_k + SU_{kt}$
ELSEIF $RSC_k$ reach maximum then seek k+1 region, do $RSC_{k+1} = RSC_{k+1} + SU_{kt}$
END IF
ELSE
For energy shortage do,
Calculate $SH_{kt} = SH_{kt} + (C_{kt} - TP_{kt})$
For energy discharge strategy do,
        If $RSC_{kt} > 0$ then retrieve energy from the largest $SD_{hrkt}$ energy Level
Update $RSC_k = RSC_k - SH_{kt}$
Do until $SH_{kt} = 0$
$DIS_{lkt} = C_{kt}$
      ELSE
Search for other k+1 regions with $RSC_{k+1t} > 0$ and do $EE_{kkt}$ ; k≠k using equation 3
Update $RSC_{k+1} = RSC_{k+1} - SH_{kt}$
Do until $SH_{kt} = 0$
$DIS_{lkt} = C_{kt}$
     ELSE
        $DIS_{lkt} = TP_{kt}$
             END
             END
        END
```

The steps of the developed algorithm start with defining the maximum capacity of storage devices and the different consumer requirement types of energy. The estimated distribution volume of energy, total consumption and the actual production volume of energy will be calculated by using the intermittent renewable sources based on the weather conditions. The surplus volume of energy will be identified after satisfying consumers' demand. The charging process of differently located storage devices will then start by identifying which devices to charge and for how long for a sustainable energy storage to face the risk of an unexpected energy demand fluctuating weather condition. The quantity of energy shortage will also be identified in case the suppliers are unable to satisfy the consumers' demand due to weather conditions. In this case, the ability of other nearby regions will be assessed first to understand and then identify which region is capable of providing backup energy and exchange it with its neighbour region under risk of energy shortage.

3. Demand Analysis and Results Discussion

In the Republic of IRAQ, there is a lack of a reliable electricity energy supply because of the increasing demand for energy, political issues, security situation and the use of currently outdated energy supply systems. This leads to hourly and/or daily power cuts, and the use of private diesel generators. This means that a competitive energy market expansion is created by new stakeholders (the owners of diesel generators). Therefore, this country requires a larger, newer, cleaner (green) and more reliable and stable supply of energy through its network along with the best management of this energy network, and hence IRAQ is selected as an example.

In this study, 5 main regions including North, Middle, South, West and East which constitutes the geography of Iraq are selected. Each region has different climate characteristics and different consumption behavior of energy and hence was selected to show the region's applicability for adoption of various renewable energy sources and contribution towards energy generation. 12 major cities (in order of population size) distributed in these 5 regions are selected including:

1- Nineveh, Salahuddin and Kirkuk - North region
2- Anbar and Diala - Middle region
3- Basrah, Misan and Thiqar - South region
4- Najaf and Kerbela – West region
5- Wasit and Qadisiya – East region

These regions including cities are selected due to the availability of their actual data including for example, consumption rates and different rates of demand of energy per day per season. The efficiency of the use of renewable energy sources in these regions/cities, including PV-solar, wind turbine and hydro varies significantly in terms of energy production/generation rates, as these rates depend on the intensity of solar radiation, wind speed and availability of reservoirs, rainfall rates and water inflow, which differ from one region/city to another.

In this section, different energy loading curves of demand of energy in different regions/cities of IRAQ are analysed. The proposed mutli agent-based optimisation system will run at a later stage and energy production will be generated and compared with the different levels of demands.

behaviour of each type of consumption of each region/city including residential, commercial, tourism, and industrial is represented by a specific and different load curve. This is because each load curve is gained from measurements or estimations of different energy consumption behaviour, which is measured hourly throughout each day for each type of consumption at different seasons. Each city's load curve is used to predict the future energy of the demand at that city and therefore, there is an individual and different load curve that represents each city's demand, where each city's demand curve is parameterised in a different way. Figure 4 depicts the peak (highest) load curve of energy of each region for selected seasons.

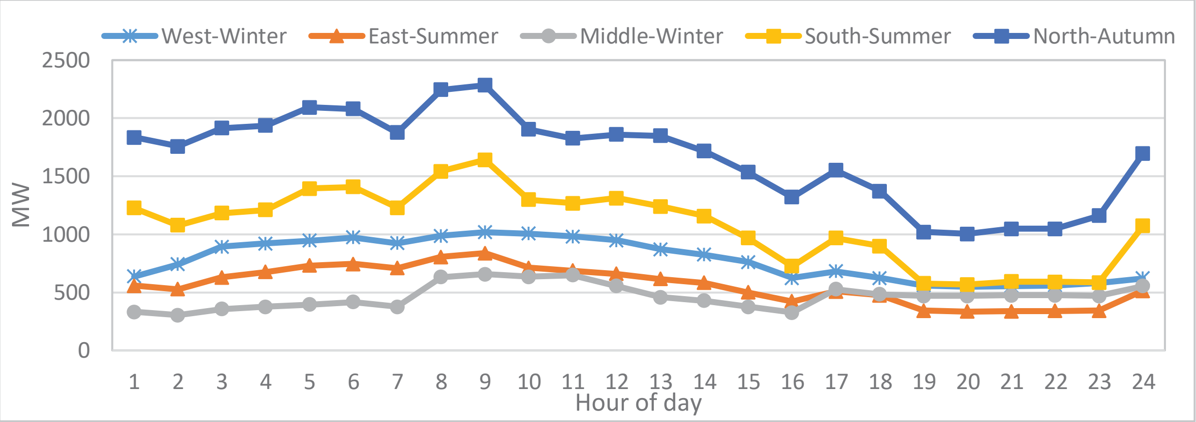

Figure 4. The daily energy peak load for 5 regions, 12 cities in IRAQ (highest load seasons)
Data source: Republic of Iraq 2018. Annual Statistical Report on Energy Electricity (in Arabic), page 26.

The highest daily load of energy is recorded in different seasons for different regions of the country. In Figure 4, it is evident that the West and Middle regions have a daily peak load in the Winter season. This is because of the increasing demand of such parts of the country for residential and industrial (seasonal) purposes, while the weather in the East and South regions of the country is very warm and humid during summer and hence the daily load of energy in Summer is the highest for residential purpose. The North area in Autumn attracts large numbers of tourists and hence, the daily demand for energy required by hotels is at the highest levels in addition to its being an agriculture season that requires additional energy levels. For the West and East regions, the energy usage varies as a result of the requirements/characteristics of each region, see Figure 5 for the difference in the consumption rates between the two regions.

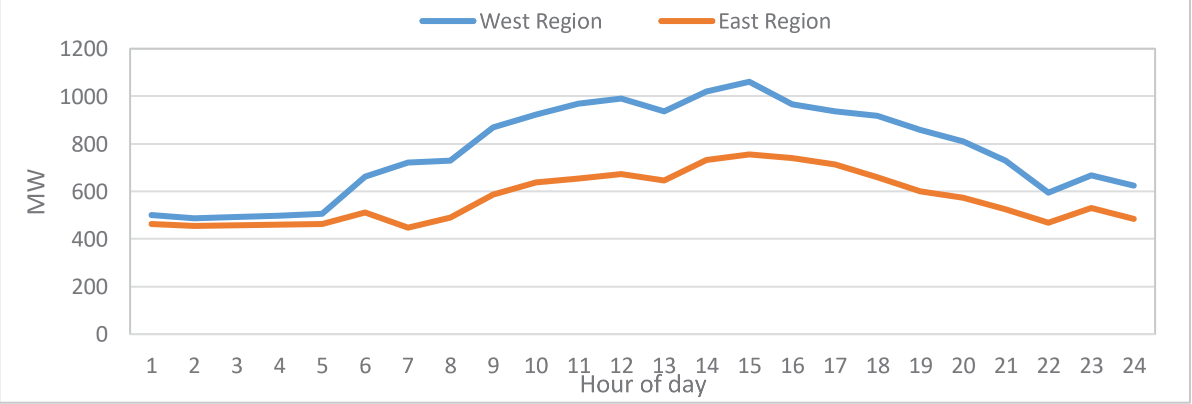

Figure 5. Consumption curve of West and East regions, 4 cities (winter/weekday)
Data source: Republic of Iraq 2018. Annual Statistical Report on Energy Electricity (in Arabic), page 26.

neighbor countries during the years. The East region including Wasit and Qadisiya cities is famous for agriculture and hence does not need high rates of energy and the load of energy in this city is consistent/stable.

In addition, it is clear from Figure 5 that in the in the off-peak times starting from 1:00am to 5:00am, the two regions have almost the same level of consumption of energy, while a higher variation in the peak load is noticed in the West region due to its tourism and its larger population.

Furthermore, consumer behaviour in terms of energy consumption is also included and modelled in such load curves. For example, the load curve of hourly energy consumption for a residential consumer on a weekday in autumn in the city of Salahuddin (North of IRAQ) is illustrated in Figure 6.

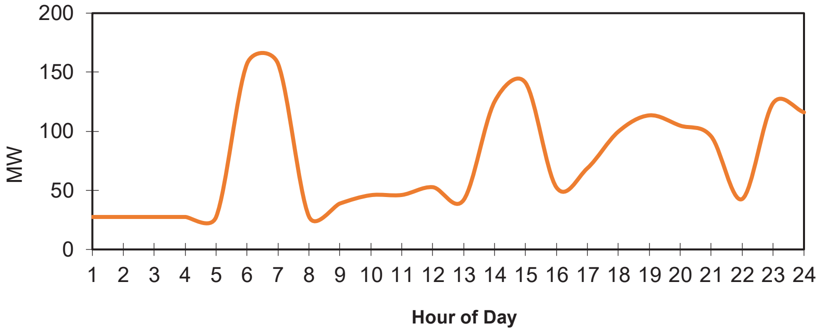

Figure 6. Consumption curve of the North region - Salahuddin city residential (Autumn/weekday)
Data source: Republic of Iraq 2018. Annual Statistical Report on Energy Electricity (in Arabic), page 26.

In Figure 6, it can be seen that after 5:00 am, residents wake up and their usage of energy increases until 8:00 am, when they leave their houses to work. After 13:00, the load increases again as the consumers are back at home. At 16:00, the consumption rate decreases as a result of some of residential consumers going out for shopping, carrying out different family visit activities and hence, consumption remains stable throughout the night.

The total energy consumption by hour for the city of Salahuddin on a weekday in the Autumn season is illustrated in Figure 5. It is clear the consumption rate of energy of this city is high due to the fact that it is an agriculture and industrial city, while when this is compared with another city, such as Ninevah city, the last is densely populated with a residential consumption of energy behavior, and hence, consumption rate is different and lower than the Salahuddin city. See Figures 7 and 8 for the difference shape of load curve between these two cities (North of IRAQ)

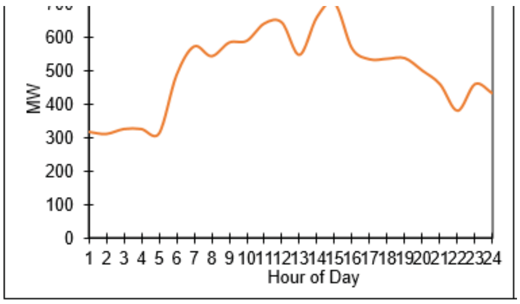

Figure 7. Total consumption curve of Salahuddin city (autumn/weekday)

Data source: Republic of Iraq 2018. Annual Statistical Report on Energy Electricity (in Arabic), page 26.

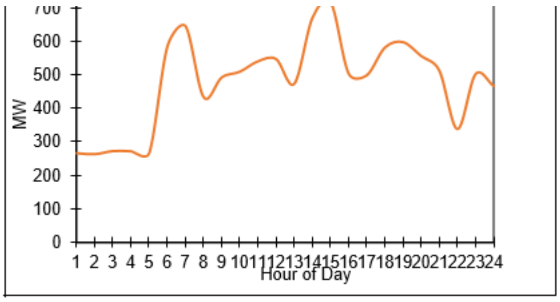

Figure 8. Total consumption curve of Ninevah city and (autumn/weekday)

Data source: Republic of Iraq 2018. Annual Statistical Report on Energy Electricity (in Arabic), page 26.

The regional demand in the hourly energy consumption for the residential users in North and South of IRAQ on a weekday in the summer season is considered as another example and presented in Figure 9.

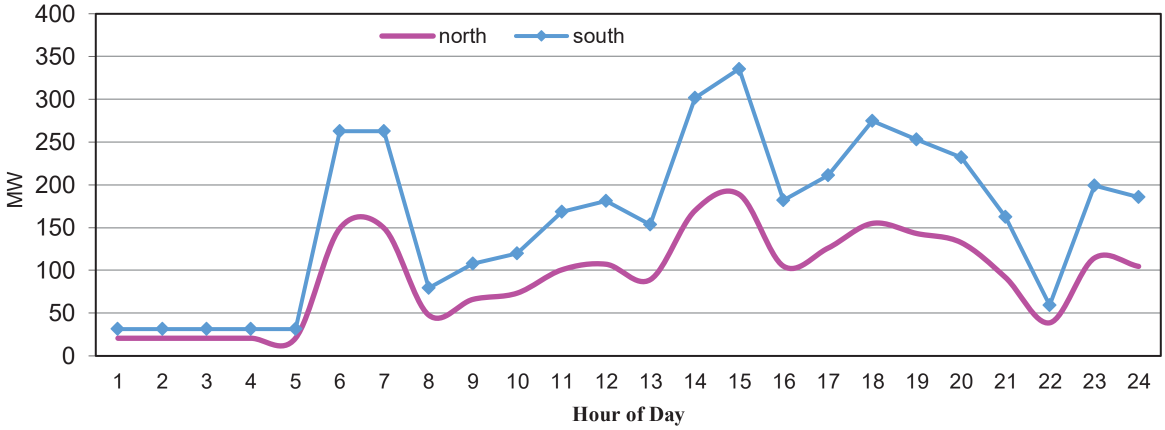

Figure 9. Consumption curve of residential (summer/weekday) for North and South of IRAQ, 6 cities

Data source: Republic of Iraq 2018. Annual Statistical Report on Energy Electricity (in Arabic), page 26.

In Figure 9, a comparison of the consumption curve of energy of both North with the South regions is presented. Because the Southern region has higher temperatures compared with the North, it has a higher residential consumption rate.

The daily consumption rate of energy (commercial) is relatively higher in Najaf city (West) rather than Wasit city (East). This is because the city of Najaf is a tourist (religious) city that attracts large numbers of people during the year, and hence higher rates of daily consumption of energy for commercial purposes including lightning of the religious places, shops, and hotels are required. Figure 10 depicts the consumption rates of energy (commercial) for both Najaf city (West) and Wasit city (East).

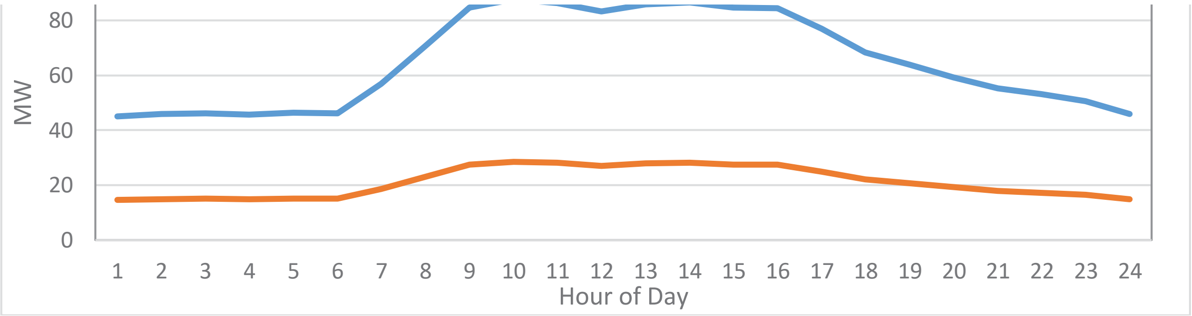

Figure 10. Consumption curve of Commercial (weekday) for West and East regions - Najaf and Wasit cities
Data source: Republic of Iraq 2018. Annual Statistical Report on Energy Electricity (in Arabic), page 26.

In Figure 10, the Wasit city (East region) shows consistent/stable consumption of energy because this region of the country requires less levels of energy for agriculture purpose and is less populous compared with Najaf city.

3.2 Results Discussion

Each region has multiple suppliers, each with different rules to provide energy to different distributors. A distributor agent has multiple options to buy energy by selecting one or more suppliers, in order to meet the equivalent consumers' energy demand. The region demand (consumer) agent including cities' demand, which varies as each city has different consumer demands. These consumers have different options to buy energy, by selecting distributors according to their sales rules. After running the developed system, its behaviour was tested by addressing the effect of *renewable energy sources on supplier selection and energy production, consumer options on supplier selection and energy purchase*, *and adoption of region exchange capability (using storage devices) on consumer demand satisfaction.* These scenarios allow us to easily vary the volumes of the energy supply from different suppliers and energy consumption by different consumers through the distributors, then run many different experiments to allow for variation of the production size and consumption of fluctuating consumers, numbers of suppliers and distributors. In these scenarios, we are exploring the effect of the variation in production against the variation in consumption on the energy exchange volume throughout regions, and furthermore, the capacity of storage devices and locations. These scenarios are discussed as follows:

3.2.1. Selection of Renewable Energy Sources

This scenario is designed to investigate the impact of investment volume of each supplier in different sources of renewable energy on the maximum storage capacity in two different regions including North and South (6 cities) that have different attributes in terms of climate and consumption rates, and hence they have been selected as an example. Each city's consumption fluctuates due to consumers' differing demand. In Table 2, the results of the North region with three suppliers and two distributors are presented.

			North region			Capacity MW
Supplier S	Source Type r	Min-Max (MW)	Nineveh c_{11}	Salahuddin c_{12}	Kirkuk c_{13}	$\mathrm{SC}_{\max}$
1	Solar	0-790	45%	45%	19%	785
	Wind	9-273.25				
2	Solar	0-237.99	32%	32%	51%	535
	Hydro	193.5-260.57				
3	Wind	16.2-427	33%	33%	19%	780
	Hydro	261.3-351.7				

In Table 2, Supplier 1 has two sources with energy storage: Solar with maximum capacity of 790 MW and Wind of 273.25 energy capacity. After implementing the system, the optimal level of storage needs in Nineveh for this supplier is found to be 353.25 (45%*785), which is more than Salahuddin and Kirkuk cities, due to the high consumption in Nineveh. In addition, the supplier needs to increase the capacity in MW of energy storage when investment in the Wind source is considered. For the South region, the results of simulation of three suppliers and two distributors are presented in Table 3.

Table 3. Output of simulation run for the South region (Basrah, Misan, Thiqar)

Details	Renewable	Production	Amount of energy storage by location			Max-Storage Capacity MW
Supplier S	Source Type r	Min-Max (MW)	Basrah c_{41}	Misan c_{42}	Thiqar c_{43}	$\mathrm{SC}_{\max}$
1	Solar	0- 928.7	47%	23%	30%	825
	Wind	18.1-1189.8				
2	Solar	0-237	28%	48%	24%	650
	Wind	16.2-1427.76				
3	Wind	8-500	47%	36%	17%	750
	Hydro	21.34-104.75				

In Table 3, it is clear that the level of the energy generated by the Wind Turbine source in the South region for the cities of Basrah, Misan and Thiqar is high due to the climate suitability of this region for using such renewable energy resource. The highest level of storage energy is achieved in the city of Basrah c_{41} because this city is the biggest in the South in terms of population size and area and hence it has a higher consumption rate of energy.

in which two regions (North and South) are investigated. In Figure 11, results of one summer weekday for three regions including Kirkuk, Nineveh and Salahuddin (North) are presented. Each city has different consumption requirements, for example, Kirkuk is an industrial city and Salahuddin is an agricultural city, however, Ninevah city has a high-density population and hence most of the energy is required by households.

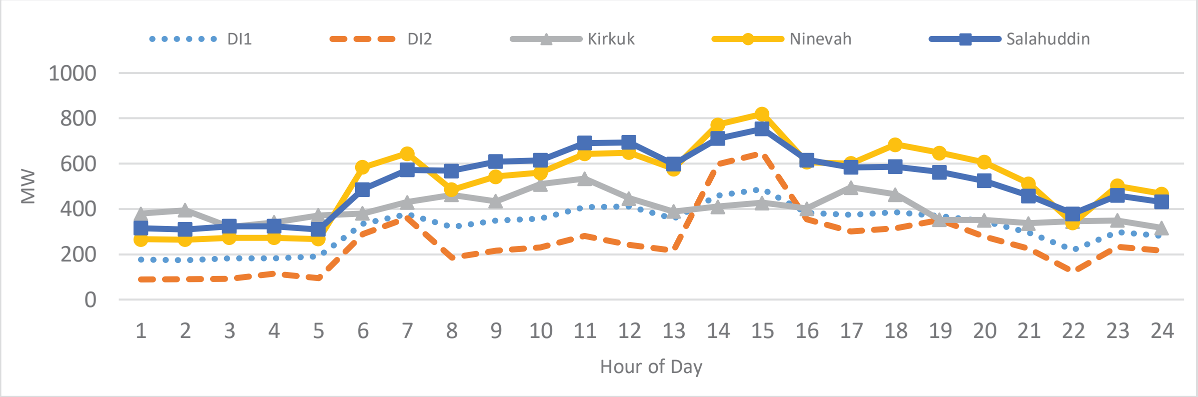

Figure 11. Comparison between energy consumption and distribution in North regions - Nineveh, Salahuddin and Kirkuk cities

In Figure 11, the difference in consumer behaviour in the three cities is reflected in their demand curves, while the shape of the demand curve of distributor 1 that has time with tariff is smoother than the distributor 2. The city with residential consumption type is more able to reduce the energy purchase in peak load time from distributor (DI_1). Figure 12 shows the comparison between energy consumption and distribution in the South region, where the weather is warm and humid during the Summer season.

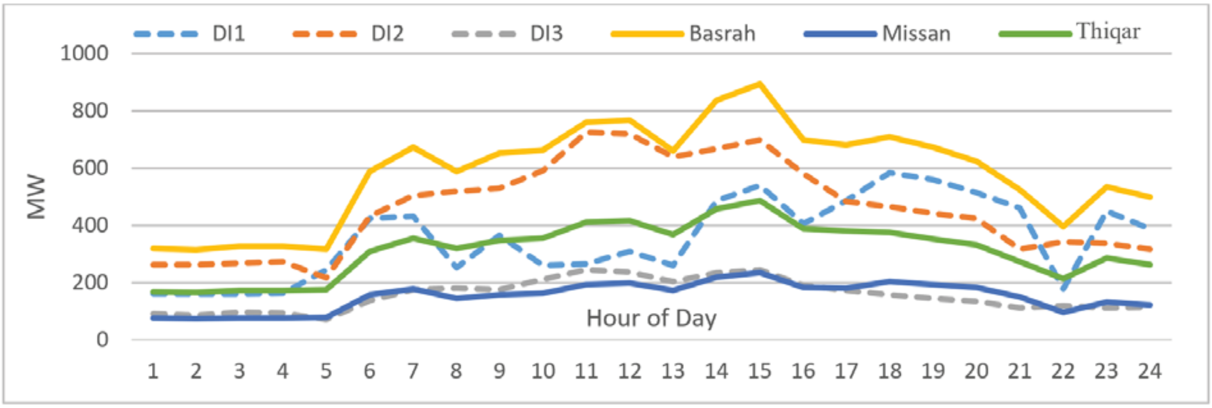

Figure 12. Comparison between energy consumption and distribution in the South region – Basrah, Missan and Thiqar cities

Each city of the South region including Basrah, Missan and Diqar has different consumption requirements; however, Basrah city has the highest consumption rate of energy because of its high-density of population and larger areas than other cities and hence most of the energy is required by households in this city.

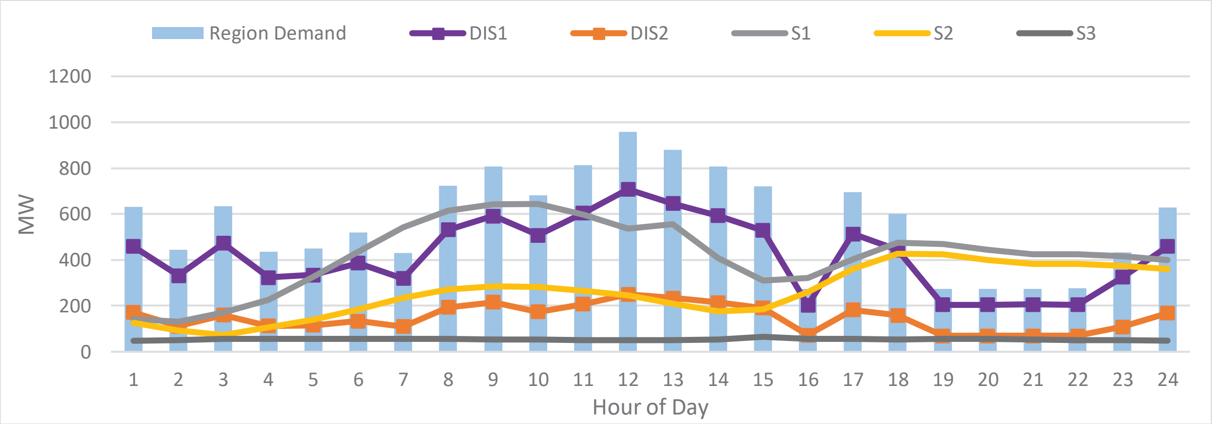

Figure 13. Comparison between energy production and consumption in the Middle region – Anbar and Diala cities

In Figure 13, it can be seen that the load curve for the energy distributed by distributor 1 fluctuates less and is smoother than the energy production of supplier 1, who shows a larger fluctuation than that of supplier 3. The load curve of distributor 2 is smoother than that of suppliers 2 and 3 respectively. These results demonstrate the impact of energy volume that the distributor purchases from each supplier on energy provided to consumers by distributors.

3.2.3. Adopting Region Exchange Capability – 5 Regions

This scenario investigates the effect of different numbers of supplier and distributors on the Region Exchange Capability under usage of storage devices to satisfy the consumer demand. It shows what optimal performance of energy exchange under specific of number of suppliers and distributors would look like. After running the proposed system, such region exchange capability becomes available. The effect of different numbers of suppliers and distributors for each region on consumer demand is identified. Table 4 presents the influence of energy surplus and shortage through different seasons as a result of the change in the number of distributors and suppliers.

Case No.	Summer		Spring		Winter		Autumn	
1	-2762.5	743	-669.7	2148	-1817	2172.1	-1625.2	616.4
2	-2549.1	901.2	-669.9	2888.5	-1232.3	2632.7	-1624.3	792.7
3	-2236.5	835.3	-614.9	2146.7	-1478	2171.9	-2011.9	502.8
4	-2064.1	898.8	-586.1	2888.4	-1060.9	2632.7	-1624	580.5
5	-2084.5	610.4	-669.9	2147.2	-1070.5	2172	-1624.1	523.7
6	-1560.2	774	-669.9	2147.2	-851.8	2172	-1624	802.7
7	-1560.2	898.8	-704.6	2888.5	-877.6	2632.7	-1624	748.8
8	-1560.2	743.8	-644.6	2292.3	-828.6	2261.1	-1624.1	802.7
9	-1560.2	1041.8	-586.1	2147.2	-829.4	2172.1	-1624.1	748.9
10	-1560.2	835.3	-614.7	2509.9	-851.8	2394.5	-1624.1	580.1
11	-1800.7	835.5	-614.7	2297.1	-1250.4	2261.1	-1711.7	555.3
12	-1655.6	1041.8	-586.1	2292.3	-806.5	2261.1	-1625	802.7
13	-1655.6	783.8	-558.4	2292.3	-771.8	2261.1	-1624.9	802.7
14	-2546	1248.3	-525.3	2494.6	-1218.3	2261.1	-1624.9	674
15	-2546	834.3	-670	2509.9	-1218.3	2394.5	-1624.9	676.8
16	-1651.5	1667	-302.9	2437.4	-745.6	2350	-1624.1	848.6
17	-1560.2	725.2	-586.1	2147.2	-869.9	2172.1	-1863.1	580.1
18	-1560.2	898.8	-586.1	2888.5	-851.8	2632.7	-1777.6	591.6
19	-1560.2	1558.1	-463.8	2147.2	-687.9	2172.1	-1624.1	848.6
20	-1560.2	804.2	-669.9	2295.5	-902.4	2172.1	-1842.8	618.8
21	-1518.8	1000.1	-262.8	2890.2	-538.7	2617.5	-1624.1	1445.1
22	-1400.1	951.8	-410.1	2671	-765.3	2546.4	-1881.1	580.0
23	-1561.3	898.8	-602.3	2888.5	-829.9	2632.7	-1624.1	1015.0
24	-2099.8	1430.1	-216.5	2651.2	-991.5	2381.9	-1624.1	698.2
25	-1252.4	1022.3	-489.4	2664.3	-576.4	2532.6	-1624.1	811.3
26	-1366.2	898.8	-320.4	2888.5	-446.8	2632.7	-1624.1	818.1
27	-1400.1	1158.4	-368	2394	-495.6	2317.2	-1778.3	784.0
28	-1743.4	865.2	-540.3	2687.2	-697.8	2445.4	-1778.3	735.5
29	-1705.3	962.4	-292.2	2768.6	-818.1	2568.9	-1778.3	659.9
30	-2467	797.1	-1847.1	2534.6	-1911.7	2458.6	-4892.2	634.0
31	-1705.6	1693.2	-423.4	2742.1	-387.8	2567.9	-1881.1	965.5
32	-1490.5	1043.5	-611.9	2464.7	-627.1	2377.3	-1624.1	1330.4
33	-1579.3	900.1	-477.7	2744.9	-505.5	2545.7	-1726.9	1278.9
34	-1432.4	1245.1	-261.5	2687.9	-680	2558.7	-1624.1	1073.9
35	-1618.2	1800.1	-237.8	2711.5	-745.1	2537.7	-1624.1	948.4
36	-2419.7	1036.7	-681	2538.6	-177.8	2396.1	-1778.3	632.8
37	-1591.6	1636.7	-317.7	2888.5	-518.5	2632.7	-1804.0	2394.3
38	-1473.8	828.7	-428.3	2444.9	-827.1	2425.2	-1701.2	994.5
39	-1507.5	855.6	-435.7	2440.1	-1229	2327.2	-2343.6	657.2
40	-1558.9	1583.4	-408.6	2468.7	-1130.9	2433.1	-2235.1	625.6
41	-1529	1395.7	-415.9	2451.9	-882.2	2358.9	-1778.3	605.5
42	-1558.9	1098.8	-540.7	2606.2	-775.1	2395.1	-1881.1	840.0
43	-1391.9	817.5	-436.5	2537.7	-702.2	2418.1	-1624.1	1025.3
44	-1586.5	1585.7	-383.7	2598.3	-913.5	2379	-1842.1	709.1
45	-1299.7	985.9	-617.1	2679.3	-893.5	2546.9	-1624.1	1112.5

South respectively. In this case, for example, the energy shortage (-2762.5 MW) is the highest compared to case 2 (-2549.1 MW) and case 6 (-1560.2 MW). This reduction in energy shortage is achieved by increasing the number of suppliers from 1 to 3 in the North and Middle regions, keeping only 1 supplier for the regions of West, East and South, and adopting the same number of distributors in case 1 for all the 5 regions.

Furthermore, cases 25 and 26 can be considered as the best ones that provide minimum shortage of energy. This is because the optimal combination of suppliers and distributors in terms of numbers per region in these cases is achieved.

4. Sensitivity Analysis

Since other methods mentioned in the literature would not have direct comparison factors that suit either the problem or the proposed model, a sensitivity analysis is conducted in order to verify the behaviour of the developed model toward different demand behaviour types according to different regions (See Figure 4). This will assist in understanding how the energy exchange levels between different regions will be affected by the fluctuations or changes in a crucial factor, such as the consumer demand. Table 5 shows a sensitivity analysis of the demand and its effect on the energy exchanged levels between different regions.

Table 5. The sensitivity analysis of demand growth on energy exchange in 5 regions, 12 cities

Region/Demand Behaviour					Season/EE (MW) Energy Exchange			
North (3 cities)	Middle (2 cities)	West (2 cities)	East (2 cities)	South (3 cities)	Winter	Spring	Summer	Autumn
Increase	Decrease	Decrease	Decrease	Oscillate	2396.3	2509.9	940.2	996.9
					-959.8	-705.3	-1538.5	-1777.2
Oscillate	Decrease	Oscillate	Oscillate	Increase	2485.1	2651.9	1426.5	-1805.0
					-705.5	-401.1	-1536.8	1048.4
Decrease	Oscillate	Increase	Oscillate	Increase	2287.2	2513.3	1347.7	1040.5
					-738.6	-408.8	-1490.4	-1776.3
Increase	Decrease	Increase	Oscillate	Oscillate	2483.2	2650.2	1239.7	1030.5
					-894.2	-546.5	-1516.9	-1774.4
Increase	Increase	Increase	Increase	Oscillate	2442	2595.4	1231.8	1030.5
					-697.9	-629.6	-1527.8	-1702.2
Oscillate	Oscillate	Oscillate	Oscillate	Increase	2431.3	2557.6	1278	1030.5
					-642.6	-596.1	-1478.6	-1777.3

It is clear from the above results in Table 5 that demand growth behaviour may also differ because of the changing weather conditions existing between different regions. Simulations demonstrate that the shortage in energy is positively correlated to both a Decrease (red) and Oscillation (orange) of the growth in demand, whereas it is negatively correlated to an Increase (red) and Oscillation in demand growth. This is clear when, for example, the value of energy shortage is reduced in the Winter (by -738.6), Spring (by -408.8), Summer (-1490.4) and Autumn (-1776.3) in case there is a Decrease, Oscillation, Increase, Oscillation and Increase in the demand growth for the North, Middle, West, East and South regions respectively.

demand types based on various renewable energy sources that are influenced by different weather changes. A new heuristic optimisation algorithm was proposed to optimise storage levels of energy at different located devices to face uncertainty of energy production and/or demand in order to cover the variable demand growth for consumers. Furthermore, the upper bound of energy storage exchange between different regions was optimised. The overall structure of the proposed system and the full integration of its components led this system to be considered as an efficient renewable energy production management and distribution planning system that can be used to solve complex scenarios of both production and distribution in the energy sector or similar type of sectors.

The results demonstrated the effect of running combinations of different numbers of suppliers and distributors for each region (5 regions, 12 cities are considered in this study) on the energy surplus value and shortage through different seasons. Furthermore, the effect can be found in the introduction of more storage devices for energy saving, which can induce an increase in consumption as a result of the rapid consumer response to lower operational costs. Progress on distributed renewables, energy efficiency and subsidy reform today will enable IRAQ, which suffers from an aggressive economy crisis, to achieve major savings in the future.

This work contributed to the formulation of several management policies on renewable energy. It is recommended that the IRAQI government should encourage suppliers of renewable energy to expand their investments in terms of increasing number of renewable energy sources in selected regions such as increasing the number of Wind Turbines in the South region, best management of the water storage in the Mosul dam along with increasing capacity of the PV-solar farms in the North and Middle regions for best production of energy levels. In the West region additional number of Wind turbines should be adopted along with larger PV-Solar farm sizes, and finally, to increase all Hydro, Wind Turbines and PV-Solar capacities in the East region. Regarding distributors, the IRAQI government would prefer the option of increasing number of distribution companies across all the 5 regions to guarantee a fair market competition for distribution companies. This will provide the customer with flexibility in identifying the lowest cost and most efficient distributor. Finally, the customer should be advised by the government to adapt its consumption behaviour to fit the available energy generated by the renewable sources. For example, increasing customer's awareness towards more efficient ways of using energy such as carry out most of the household activities such as vacuum, ironing, and washing etc. during the day and leave other minor usage of energy such as lighting for the night times.

As a future work, larger scale problems including higher number of cities, distributors and suppliers could be modeled and investigated for more robust and generalized scenarios. More influence of weather during the day could be modelled and tested on the energy production level and the chosen sources of energy for more realistic plans of energy distribution.

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