Renewable and Sustainable Energy Reviews 66 (2016) 1–9

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Sustainable renewable energy resources utilization in rural areas

Abraham Debebe Woldeyohannes [a,*], Dereje Engida Woldemichael [b], Aklilu Tesfamichael Baheta [b]

[a] Caledonian College of Engineering, PO Box 2322, CPO Seeb 111, Oman
[b] Universiti Teknologi PETRONAS, 32610 Bandar Seri Iskandar, Perak, Malaysia

ARTICLE INFO

Article history:
Received 29 November 2014
Received in revised form
5 March 2016
Accepted 4 July 2016
Available online 29 July 2016

Keywords:
Renewable Energy
Optimization
Transportation algorithm
Transportation model
Resource allocation

ABSTRACT

This paper aims to address the issues related to renewable energy (RE) resources optimization in the areas where providing power from main grid is challenging. A region having ten different sub-regions has been considered for the optimization based on transportation algorithm. The partitions are made based on customer segmentation to ensure that various scattered demand for the RE is represented at the best location to enhance energy optimization by minimizing the energy loss during transmission. Three cases, i.e., when the demand and supply are equal, when there is more demand than supply, and when the supply is greater than demand are considered for the analysis. For the first case, the total energy requirement and the energy potential available from the regions is 1.26 GW h/year. For this scenario, most of the regions (seven regions) received the energy requirements from single RE source; three regions received the required energy from two different RE sources. The annual optimized total cost of energy supply for this scenario is determined to be $187,961.68. Results obtained from the transportation model have been validated based on other RE studies in the area. For the similar case study considered, it is noted that the minimized total cost obtained using transportation algorithm depicts an improvement in cost over integrated renewable energy system (IRES) models. The developed optimization model could be used as a decision making support tool to evaluate and select various alternative renewable energy resources and to determine the optimal locations for developing these resources.

© 2016 Published by Elsevier Ltd.

Contents

* Corresponding author.
E-mail addresses: debebeabraham@yahoo.com, abraham@caledonian.edu.om (A.D. Woldeyohannes).

http://dx.doi.org/10.1016/j.rser.2016.07.013
1364-0321/© 2016 Published by Elsevier Ltd.

1. Introduction

The increase in demand for energy consumption coupled with the depletion of fossil fuels enhanced the need for rapid development of renewable energy (RE) sources to satisfy demand. However, the proportion of the renewable energy in the overall energy utilization for various countries is still at the minimal stage. RE is required for different activities such as lighting, heating and cooking which might come from various sources such as biomass, solar, wind, and hydropower. The development costs for satisfying the energy requirement at the specific area using various alternative energy sources are different. The challenge in energy resource management is deciding how to utilize the available RE resources by satisfying the need for energy requirement. In order to ensure that sustainable energy supply for the regions are met, it is important to develop a suitable optimization model for evaluating and selecting the alternative RE resources.

There is a sign of improvement regarding the use of renewable energy in the last five decades because of the environmental, social and economic factors [1–4]. In order to ensure that RE resources are optimized, there have been many attempts by researchers to enhance the sustainability and RE utilizations. Optimization of integrated renewable energy system (IRES) model is one of the methods to manage the alternative renewable energy resources efficiently. Akella et al. [5] developed a model to optimize energy utilization from solar, wind, hydropower, and biomass for remote area of Uttaranchal State in India for 12 un-electrified villages. Multi-objective optimization of a mixed renewable system with demand-side management was also proposed by Moura [6], Omu et al. [7], Fuso et al. [8] and Ashouri et al. [9].

Xydis and Koroneos [10] developed a linear programming approach for the optimal planning of a future energy system. The authors optimized the energy needs in each administrative and geographical region using RE sources and at the same time to define the remaining available space for energy recovery units from municipal solid waste in each region to participate in the energy system. Jain [11], Mahapatra et al. [12] and Agarwal et al. [13] developed integrated rural energy centers based on renewable energy sources to meet the energy needs of remote rural areas. Katti and Khedkar [2] proposed the use of renewable energy technologies (RET) in an integrated way and simulates on the removal of barriers on implementation strategies in the region of South Asia in general and India in particular.

Another option to optimize the energy utilization is to use the principles of hybrid energy system where the renewable energy resources are combined with conventional energy resource to fulfill the demand requirements. The hybrid energy system developed by Gupta et al. [14] consists of six procedures for optimizing the energy utilization in remote areas. The procedures consist of clustering the rural areas, assign the demand, assessing the supply, estimation of the unit cost, sizing and optimization and model formulation. The limitations of this paper are the use of conventional energy resources and the research focus only on the cost aspects. Gupta et al. [15,16] also proposed the hybrid energy system optimization for rural areas by combining the use of renewable energy resources with that of the conventional energy resources. The optimization of hybrid energy system based on integer programming is also reported in Gupta et al. [16,17].

Balasubramanian and Cellatoglu [18] proposed combination of renewable energy sources like solar, wind and wave energy for satisfying the energy requirement of Cyprus with the aid of designated apparatus. Iniyan and Sumathy [19] developed renewable energy model for optimum allocation of renewable energy resources in India based on survey and forecasting for various end users. The use of distributed energy resources (DER) has been proposed as possible solution to energy and environmental challenges in several countries. DER is multi-objective problem where several objectives need to be optimized with some of the objective function conflicting as reported in Alarcon et al. [20].

Omun et al. [21] developed a distributed energy resource system optimization. The authors proposed a mixed integer linear programming (MILP) model for the design (i.e. Technology selection, unit sizing, unit location, and distribution network structure) of a distributed energy system that meets the electricity and heating demands of a cluster of commercial and residential buildings while minimizing annual investment and operating cost. Buoro et al. [22] developed a multicriteria optimization of a distributed energy supply system for an industrial area. The multi-objective optimization is based on a MILP model and takes into account objective function as a linear combination of the annual cost for owning, maintaining and operating the whole system and the CO_2 emissions associated to the system operation.

Multi-objective Intelligent Energy Management for a Micro grid is proposed by Chaouachi et al. [23,24]. The proposed multi-objective intelligent energy management minimizes the operation cost and the environmental impact of a micro grid, taking into account its pre operational variables as future availability of renewable energies and load demand. Hochloff and Braun [24], Buoro et al. [22] and Omun [21] developed MILP for optimizing biogas plants with excess power unit and storage capacity.

Though there is significant improvement in addressing the issue of renewable energy optimization through various optimization tools, there are still long ways to enhance the renewable utilization in remote areas for sustainability. One of the main challenges is that most of the developed optimized renewable energy models are not fully addressing the issue of energy optimization from the localized perspective. The issues of optimized energy resource utilization are highly localized as the availability and potential of energy resources are related to the geographic location. As a result, a model developed for one country might not be directly applicable to other countries. Moreover, achieving local energy demand with nearest possible energy resources could result in sustainable utilization of energy resources. It also reduces significant amount of energy that will be lost during transmission process.

This paper proposes a suitable renewable energy resources utilization model for rural areas which minimizes the overall cost of development and operation of RE sources while satisfying the demand and supply requirements on the basis of transportation model. A case study area having ten subdivisions based on customer clustering is considered for the implementation of the model.

2. Case study area

2.1. Problem description

The development costs for satisfying energy requirement at the specific area using various alternative energy sources are different. The challenge in energy resource management is deciding how to

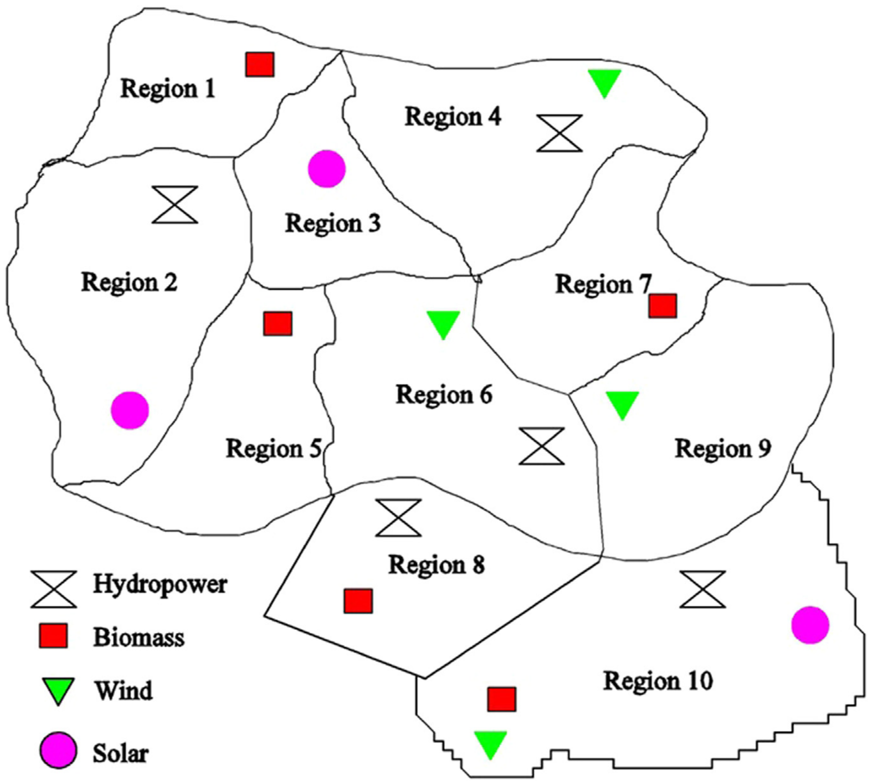

Fig. 1. Typical geographical area with potential energy sources distribution.

utilize the available resources by satisfying the need for energy requirement. In order to have a sustainable energy supplies and utilization, it is necessary to develop a suitable optimization model for evaluating and selecting the various alternative energy resources. From sustainable point of view, in areas where there are limited sources of renewable energy with scattered population density, it is important to manage the resources efficiently.

Fig. 1 shows the case study area with different RE potential. The case study area contains ten subdivisions having different demand for energy and RE potential. The partitions are made based on customer segmentations to ensure that various scattered demand for the renewable energy is repressed at the best location to enhance energy optimization by minimizing the energy loss during transmission.

Each region might experience various demand and supply scenarios depending on season and environmental conditions. In order to come up with detailed energy demand profile for each region, it is important to take into consideration several factors such as type of appliances used, number of occupants in each house, lifestyle pattern, culture, and house occupation period. Furthermore, the annual demand curve can also be significantly affected by seasonal variations as reported in [25]. The methodology developed by Kadurek et al. [26] to predict the residential load profile for the low voltage network distribution system design can also be used to come up with an appropriate load profiling of a particular region.

For this case study, the demand profile of each region is estimated based on average annual consumption. The unit generation and transmission costs are also considered and they are based on the average annual cost. In order to extend the application of the proposed model for demand and supply scenario on daily or based on seasonal variation, it is essential to characterize all parameters such as unit cost of generation and transmissions accordingly.

2.2. Renewable energy potential

Depending on the geographic location, different subdivisions of the case study have various demand and renewable energy potential. As depicted in Fig. 1, some subdivision (Region 10) contains RE potential of all types considered in this study, while others are limited to only one type of renewable energy resource (Region 1, Region 3, Region 5, Region 7 and Region 9). The potential for various RE resources such as solar, wind, hydropower and biomass at the specific subdivision is estimated based on the geographic locations and metrological data.

RE resources potential can be significantly affected by seasonal variations. For instance, solar RE potential is more abundant in summer compared to winter seasons. Other form of RE potential sources such as hydro power can also be affected by seasons. The analysis in this case study is conducted based on average RE resource supply potential. The model can also be easily extended to various RE supply curve for each individual region.

2.2.1. Solar energy

Solar energy is one of the potential renewable energy sources abundant in most part of the world. However, the daily solar radiation received at each location depends on the geographic location. For instance, Malaysia which is geographically close to the equator receive a daily average minimum of solar irradiation of 4.21 kW h/m^2 and daily average maximum of 5.56 kW h/m^2 [27]. On the other hand, Oman which is geographically located in Middle East receive a daily average solar irradiation of 5.91 kW h/m^2 [28]. There is plenty of solar RE source at various locations depending on the geographical sites. However, the availability/scarcity of the solar RE source depend on the amount of investment made on the resources.

The annual solar radiation potential for each subdivision is estimated by taking into consideration the efficiency of the photovoltaic (PV) system. The average efficiency of the conventional silicon cell PV system is assumed to be 14% as suggested by [29]. The yearly total solar irradiation is calculated from the annual average daily solar radiation. For instance, the annual solar irradiation for Malaysia is determined based on the average daily solar irradiation as 1783.03 kW h/m^2 [27]. Similarly, the average solar irradiation for Oman is determined to be 2157.15 kW h/m^2 [28].

2.2.2. Wind energy

The other potential renewable energy resource is wind energy. Wind energy potential various from place to place depending on the geographical locations and terrains of the regions. In Oman, as reported in [28], a minimum mean annual wind speed of 5.1 m/s and maximum of 6.3 m/s are observed at 10 m station height for Qairoon Hariti, Thumrait, Masirah, Joba and Sur. As reported in [30], the wind shear at the ground causes the wind speed to increase with height. Accordingly, the maximum power generated based on wind energy is estimated using the assumptions in [30,31]. Hence, the annual estimated wind energy at 80 m above the ground level could reach 4400 kW h/ m^2 which is reported at Thumrait station [28].

2.2.3. Mini hydro energy

Hydroelectricity is one of the most mature forms of renewable energy, providing more than 19% of the world's electricity consumption from both large and small power plants. Countries such as Brazil, the United States, Canada and Norway produce significant amounts of electricity from very large hydroelectric facilities [32]. Worldwide mini hydropower or small-scale hydropower projects have become more popular because of their low costs, reliability and environmental friendliness. Studies show small scale mini-hydro power generation is economically viable if the projects are combined with the additional benefits of flood and irrigation control as well as encouraging tourism [33]. Hydropower energy option is very limited for the areas where the annual rain fall is minimal. Middle East countries such as Oman can only enjoy 125 mm amount of rainfall. On the other hand, Malaysia which is tropical country could enjoy 2875 mm of rain fall annually [34]. Hence, hydropower RE source is highly dependent on the geographical location similar to solar RE source.

2.2.4. Biomass

Biomass is one of the alternative RE resources in the area where there are plenty of potential for palm oil plantations. Currently million hectare of land in Malaysia is occupied with palm oil plantation generating huge quantities of biomass. As a result, biomass from palm oil industries appears to be very promising alternatives sources of raw material including renewable energy in Malaysia [35]. Malaysian government launched the Small Renewable Energy Power Program (SREP) in 2001. This programme was the first step to encourage and intensify the utilization of renewable energy in power generation. Under SREP, utilization of all types of renewable energy including biomass, biogas, municipal waste, solar, mini-hydro and wind is allowed, however, maximum allowable electricity to be fed to the national grid is only 10 MW [33,35].

3. Model formulation

There are various operations research models applied in energy sector [6,36–38]. The problem of optimal allocation of renewable energy resources in rural areas can be done with the aid of transportation model. This paper proposes the transportation model as a new approach in order to optimally allocate the renewable energy resources in rural areas.

Generally, transportation problem arises in the distribution of material between different locations. The main challenge in the transportation problem is the determination of the minimum cost of shipping material from a set of sources to a set of destinations, given constraints on the supply at each source and the demand at each destination. The detail on the transportation modeling can be obtained from [39].

Meeting the energy requirement of society at rural regions from various renewable energy resources could be modeled as transportation model as reported in [40]. There is a similar analogy which is observed in transpiration problem with that of satisfying the energy requirement. Though RE sources such as solar energy is abundantly available, the investment made on solar energy make its potential as limited source. Satisfying the energy requirement from the areas where the RE sources are not available will result high transmission cost in addition to the generation cost as discussed in detail in Sections 3.1 and 3.2.

Let x_{ij} represents the amount of energy allocated from energy source i to energy demand station j. C_{ij} represents the cost equivalent of generating and delivering a unit amount of energy from source i to demand station j. D_j represents the renewable energy demand station at remote area j. S_i represents the renewable energy supply station at remote area i.

The optimization problem for optimum utilization of renewable energy resources with four RE resources and ten regions can be expressed as:

Objective function:

$$\text{Minimize: } Z = \sum_{i=1}^{4}\sum_{j=1}^{10} C_{ij}X_{ij}. \tag{1}$$

Subject to:

Energy supplier side constraints:

$$\left.\begin{aligned} X_{11} + X_{12} + \ldots + X_{110} &\le S_1 \\ X_{21} + X_{22} + \ldots + X_{210} &\le S_2 \\ X_{31} + X_{32} + \ldots + X_{310} &\le S_3 \\ X_{41} + X_{42} + \ldots + X_{410} &\le S_4 \end{aligned}\right\} \tag{2}$$

Energy demand side constraints:

$$\left.\begin{array}{lllllc} X_{11}+ & X_{21}+ & X_{31}+ & X_{41} & \ge & D_1 \\ X_{12}+ & X_{22}+ & X_{32}+ & X_{42} & \ge & D_2 \\ X_{13}+ & X_{23}+ & X_{33}+ & X_{43} & \ge & D_3 \\ X_{14}+ & X_{24}+ & X_{34}+ & X_{44} & \ge & D_4 \\ \vdots & \vdots & & \vdots & & \vdots \\ X_{110}+ & X_{210}+ & X_{310}+ & X_{410} & \ge & D_{10} \end{array}\right\} \tag{3}$$

The non-negative constraints:

$$X_{ij}\,,\quad C_{ij} \ \ge\ 0. \tag{4}$$

There are four potential sources which include solar, wind, biomass and hydropower. The region contains clusters of ten various subdivisions having different demand requirement for energy. Fig. 2 shows the different scenarios where the energy demand at various regions is satisfied based on the available source of renewable energy potentials.

In order to fully apply the developed transportation model, it is essential to assess the renewable energy supply and demand for the selected pilot area. Furthermore, the unit energy delivers cost (C_{ij}) for delivering a kWh of energy to the required demand station has to be determined for complete analysis based on transportation model. The following section discusses the demand, supply and unit cost of delivering energy to demand station for the selected rural area.

3.1. Renewable energy demand and supply

As depicted in Fig. 1, the study area considers 10 sub-regions (regions R1–R10). Each region has various renewable energy potential.

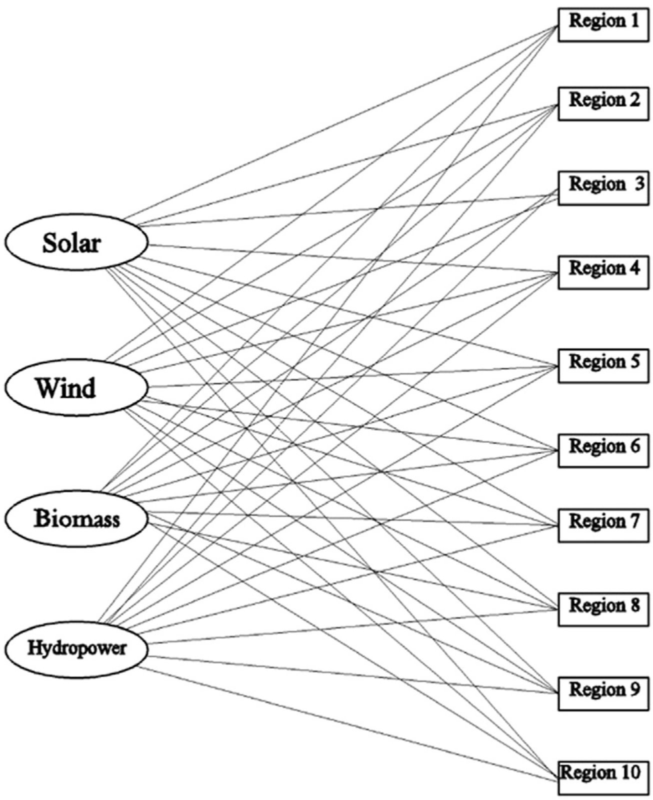

Fig. 2. Potential for fulfilling the demand requirement.

The daily energy consumption for individual household is estimated taking into consideration the various facilities such as lumps, refrigerators, ceiling fans, TV, and microwaves. The total demand for the energy was estimated taking into considerations the number of population in the region, the availability of public facilities such as schools, hospitals, police stations and other public infrastructures.

Table 1 shows the renewable energy supply potential and the corresponding demands for the study area where the demand for energy requirement is equal to the available RE resources. As shown in Table 1, there are five hydro stations (R2, R4, R6, R8 and R10), three solar energy station (R2, R3 and R10), four wind turbine stations (R1, R5, R7 and R8) and four biomass plants (R1, R5, R7 and R8).

Three different scenarios were considered. The first scenario considered is when the demand and supply are equal. In this scenario, all the energy requirements at each subdivision can be satisfied. The delivery or supply potentials and total demands for each region for this scenario are shown in Table 1. For instance, Region R1 has only biomass potential which is 87,500 kW h per year. The corresponding annual energy requirement for R1 is 82,637.24 kW h. R1 is having excess energy to be supplied to other regions to satisfy their energy demand requirement. The total annual energy requirement and the total annual potential energy available from the regions is 1,260,748.08 kW h.

Table 2
Renewable energy potential and demand (Supply is less than Demand).

Region	*Hydro [kW h/year]*	*Solar [kW h/year]*	*Wind [kW h/year]*	*Biomass [kW h/year]*	*Total resources [kW h/year]*	*Demand [kW h/year]*
R1	NA	NA	NA	87,500	87,500	82,637.24
R2	85,000	85,000	NA	NA	170,000	85,486.8
R3	NA	85,000	NA	NA	85,000	85,486.8
R4	90,000	NA	90,000	NA	180,000	82,637.24
R5	NA	NA	NA	90,000	90,000	235,000
R6	50,000	NA	50,000	NA	100,000	120,500
R7	NA	NA	NA	68,000	68,000	137,000
R8	27,000	NA	NA	104,000	131,000	143,500
R9	NA	NA	38,000	NA	38,000	117,000
R10	68,000	68,000	68,000	NA	204,000	97,500
Total	320,000	238,000	246,000	349,500	1,153,500	1,186,748.08

The second scenario considered for the analysis is when the total demand for energy is higher than the total RE resources available. Table 2 shows the total available renewable energy resources and total energy demand for this scenario. In this case, the total energy demand is 1,186,748.08 kW h while the total energy supply is only 1,153,500 kW h. It is obvious that the demand will not be satisfied for this scenario as there less energy supply from the available resources.

The third scenario considered for the analysis is when the energy supplied is higher than that of the total energy demand. Table 3 shows the detail of total energy supply and total energy demand requirement for this scenario. For this scenario, the total energy requirement is 1,086,748.08 kW h while the total energy supply is 1,360,748.08 kW h.

3.2. Renewable energy unit cost

In order to complete the transportation model, the amount of energy delivered per kWh from sources to demand stations has to be determined. The unit cost of generations is determined by taking into considerations the initial investment, replacement cost, operating and maintenance cost. Furthermore, the information in [28,41] was adopted to estimate the unit energy deliver cost from the source to demand stations. The assumption used in the transportation cost for energy sector is that, when the energy is produced in one region and supplied to the other region, a transmission cost will be incurred in addition to the generation

Table 1
Renewable energy potential and demand (Supply and demand are equal).

Region	*Hydro [kW h/year]*	*Solar [kW h/year]*	*Wind [kW h/year]*	*Biomass [kW h/year]*	*Total resources [kW h/year]*	*Demand [kW h/year]*
R1	NA[a]	NA	NA	87,500	87,500	82,637.24
R2	85,000	85,000	NA	NA	170,000	85,486.8
R3	NA	85,000	NA	NA	85,000	85,486.8
R4	90,000	NA	90,000	NA	180,000	82,637.24
R5	NA	NA	NA	90,000	90,000	135,000
R6	50,000	NA	50,000	NA	100,000	294,500
R7	NA	NA	NA	68,000	68,000	137,000
R8	134,248.08	NA	NA	104,000	238,248.08	143,500
R9	NA	NA	38,000	NA	38,000	117,000
R10	68,000	68,000	68,000	NA	204,000	97,500
Total	427,248.08	238,000	246,000	349,500	1,260,748.08	1,260,748.08

[a] If the region doesn't have the potential for RE or it is too expensive to develop.

Table 3
Renewable energy potential and demand (Supply is greater than Demand).

Region	*Hydro [kW h/year]*	*Solar [kW h/year]*	*Wind [kW h/year]*	*Biomass [kW h/year]*	*Total resources [kW h/year]*	*Demand [kW h/year]*
R1	NA	NA	NA	87,500	87,500	82,637.24
R2	85,000	85,000	NA	NA	170,000	85,486.8
R3	NA	85,000	NA	NA	85,000	85,486.8
R4	90,000	NA	90,000	NA	180,000	82,637.24
R5	NA	NA	NA	190,000	190,000	135,000
R6	50,000	NA	50,000	NA	100,000	120,500
R7	NA	NA	NA	68,000	68,000	137,000
R8	134,248.08	NA	NA	104,000	238,248.08	143,500
R9	NA	NA	38,000	NA	38,000	117,000
R10	68,000	68,000	68,000	NA	204,000	97,500
Total	427,248.08	238,000	246,000	449,500	1,360,748.08	1,086,748.08

Table 4
Energy delivery cost ($/per kWh).

Energy source	*Regions*									
	R1	*R2*	*R3*	*R4*	*R5*	*R6*	*R7*	*R8*	*R9*	*R10*
Hydropower	0.09	0.08	0.09	0.08	0.09	0.08	0.09	0.08	0.09	0.08
Solar	0.45	0.41	0.41	0.45	0.45	0.45	0.45	0.45	0.45	0.41
Wind	0.09	0.09	0.09	0.08	0.09	0.08	0.09	0.09	0.08	0.08
Biomass	0.11	0.11	0.11	0.11	0.10	0.11	0.10	0.10	0.11	0.11

Table 5
Optimized RE resource allocations (Demand is equal to Supply).

Regions	*Energy supply [kW h/year]*				*% of energy received*
	Hydropower	*Solar*	*Wind*	*Biomass*	
R1	–	–	82,637.24	–	100% wind
R2	–	85,486.80	–	–	100% solar
R3	–	85,486.80	–	–	100% solar
R4	82,637.24	–	–	–	100% hydropower
R5	–	–	–	135,000.00	100% biomass
R6	248,137.24	–	46,362.76	–	84.26% hydro-power, 15.74% wind
R7	–	–	–	137,000.00	100% biomass
R8	66,000.00	–	–	77,500.00	45.99% hydro-power, 54.01% biomass
R9	–	–	117,000.00	–	100% wind
R10	30,473.60	67,026.40	–	–	31.25% hydro-power, 68.75% solar

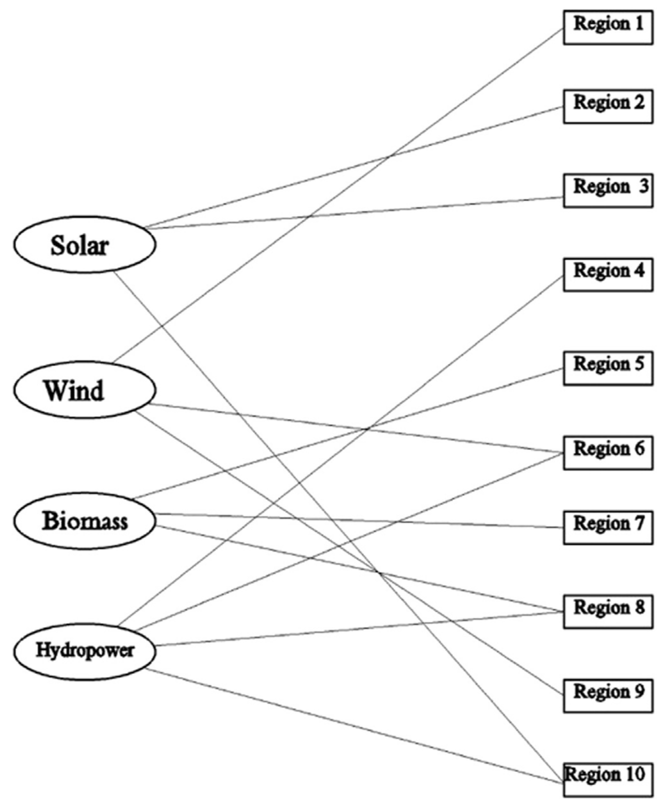

Fig. 3. Optimal RE resource allocations.

cost. The transmission costs include the development of infrastructure facilities for transmitting energy from one region to the other as well as the transmission losses during the process. It is assumed that the generation cost will be increased by 10% for delivering kWh of energy to demand station if the region doesn't have the particular energy potential. Table 4 shows the energy delivery cost per kWh from energy sources to demand stations.

4. Results and discussions

4.1. The optimization processes

The proposed model could be optimized with the help of various relevant software packages such as LINDO, LINDO API, LINGO, HOMER, VIPOR, TORA, MS Excel Solver and others. MS Excel Solver is used in this paper to optimize the proposed energy optimization

Table 6
Optimized RE resource allocations (Supply is less than Demand).

Regions	*Energy supply [kW h/year]*				*% of energy received*
	Hydropower	*Solar*	*Wind*	*Biomass*	
R1	–	–	71,889.16	–	87% wind, 13% Demand unmet
R2	–	85,486.80	–	–	100% solar
R3	–	85,486.80	–	–	100% solar
R4	82,637.24	–	–	–	100% hydropower
R5	–	–	–	212,500.00	90.43% biomass, 8.57% demand unmet
R6	63,389.16	–	57,110.84	–	52.61% hydro-power, 47.39% wind
R7	–	–	–	137,000.00	100% biomass
R8	143,500.00	–	–	–	100% hydropower
R9	–	–	117,000	–	100% wind
R10	30,473.6	67,026.4	–	–	31.25% hydropower, 68.75% solar

Table 7
Optimized RE resource allocations (Supply is greater than Demand).

Regions	*Energy supply [kW h/year]*				*% of energy received*
	Hydropower	*Solar*	*Wind*	*Biomass*	
R1	–	–	–	82,637.24	100% biomass
R2	–	–	–	85,486.80	100% biomass
R3	–	–	–	85,486.80	100% biomass
R4	–	–	–	82,637.24	100% biomass
R5	–	–	21,748.08	113,251.92	16.11% wind, 83.89% biomass
R6	–	–	120,500.00	–	100% wind
R7	–	33,248.08	103,751.92	–	24.27% solar, 75.73% wind,
R8	–	143,500.00	–	–	100% solar
R9	55,748.08	61,251.92	–	–	47.65% hydropower, 52.35% solar
R10	97,500.00	–	–	–	100% hydropower

problem using transportation algorithm. The main challenge in the implementation of the transportation model is the determination of the coefficient C_{ij} which is a function of the total capital cost, the availability of energy sources, the distance between the source and the demand station, the specific useful life of the energy investment, the yearly maintenance cost, and other factors.

The optimized energy resource allocation for the regions is determined on the basis of the RE demand and supply for the regions shown in Tables 1–3 and the cost of delivering RE resource per kWh shown in Table 4. Three different cases were considered for the detail implementation of the model for RE resource allocations.

4.2. Case 1 – energy supplied is equal to the required demand

In this case, the demand for energy requirement and the amount of energy supplied are equal to 1,260,748.08 kW h as shown in Table 1. The optimization performed for this scenario results an optimal allocation of RE resources with all demand at each region achieved. The optimal allocations for each region are shown in Table 5.

The final RE resource allocation to minimize the cost is shown in Fig. 3. As depicted in the figure, though there is potential for one region to receive energy from four different resources, i.e., solar, hydropower, wind and biomass, it is observed that most regions (R1, R2, R3, R4, R5, R7 and R9) received their energy from only one type of RE source. On the other hand, three regions (R6, R8, & R10) achieved their energy demand from two different RE resources with various percentages. The total cost of energy supply for this scenario is determined to be $187,961.68.

4.3. Case 2 – the energy supplied is different from demand

In this case, the demand for energy requirement and the amount of energy supplied are different. There are two scenarios under this category. The first scenario is the case where the demand is larger than the amount of RE resource provided as shown in Table 2. For this scenario, the total demand for the study area is estimated to be 1,186,748.08 kW h while the amount supplied from all RE resources is estimated to be 1,153,500 kW h. There is energy deficit of 33,248.08 kW h which is 2.8% of the demand required. The second scenario is the case where the amount of RE supplied is higher than the demand required which is shown in Table 3. For this scenario, the total demand for the study area is estimated to be 1,086,748.08 kW h while the amount supplied from all RE resources is estimated to be 1,360,748.08 kW h. There is RE surplus of 274,000 kW h which is 25.21% of the demand required.

Both scenarios are regarded as unbalanced transportation problem. Hence, the optimization process in this type of RE resource allocation is analyzed based on the unbalanced transportation algorithm. A dummy RE resource was introduced for the scenario where the supplied energy is less than the energy required while a dummy RE demand station was introduced for the scenario where the RE resource supplied is greater than the required demand. Table 6 shows the optimized RE resource allocation for the scenario where the demand is higher than the RE supplied. It is observed that R1 and R5 have unmet demand requirement of 13% and 8.57%, respectively, because of the energy deficit. For this scenario, the total cost of energy supply for the study area was determined to be $179,296.92.

Table 7 shows the optimized RE resource allocation for the scenario where the demand is less than the RE supplied. It is observed that the energy requirement of the entire region is satisfied as there is surplus amount of energy. For this scenario, the total cost of energy supply is determined to be $136, 0755.24.

4.4. Results verifications

The proposed optimization model was verified based on the case study for Uttaranchal State in India conducted in [5]. Table 8 shows the raw data of un-electrified for the case study area conducted in [5]. The un-electrified villages consist of 12 different villages with various RE potential demand requirement. The hydropower potential is limited to only six villages as shown in Table 8. Based on the information of demand and available resources,

Table 8
Data of 12-un-electrified villages of ZONE 4 [5].

Village name	Hydro *[kW h/year]*	Solar *[kW h/year]*	Wind *[kW h/year]*	Biomass *[kW h/year]*	Total resources *[kW h/year]*	Demand *[kW h/year]*	85% Demand *[kW h/year]*
Silla (V1)	2851	1863	1270	13,508	19,492	118,856	101,027.6
Nihaldanda (V2)	NA	1863	1270	1805	4938	18,455	15,686.75
Dandagaon (V3)	NA	1863	1270	2118	5251	16,252	13,814.2
Gawalidanda (V4)	NA	1863	1270	1529	4662	20,405	17,344.25
Chifalti (Chiryali Danda) (V5)	1369	1863	1270	2623	7125	19,164	16,289.4
Jaintwari (V6)	NA	1863	1270	3139	6272	29,071	24,710.35
Talyakatal (V7)	NA	1863	1270	3958	7091	34,879	29,647.15
Sandna laga Gawali Danda (V8)	15,263	1863	1270	23,142	41,538	43,234	36,748.9
Ragargaon (V9)	73,715	1863	1270	508,807	585,655	224,441	190,774.85
Airalgaon (V10)	NA	1863	1270	5883	9016	43,696	37,141.6
Sera (V11)	8672	1863	1270	51,826	63,631	111,445	94,728.25
Kund (V12)	26,295	1863	1270	23,043	52,471	127,746	108,584.1
Total	128,165	22,356	15,240	641,381	807,142	807,644	686,497.4

Table 9
Energy delivery cost ($per kWh) [5].

Energy source	Villages											
	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12
Solar	0.244	0.244	0.244	0.244	0.244	0.244	0.244	0.244	0.244	0.244	0.244	0.244
Hydro-power	0.024	0.026	0.026	0.026	0.024	0.026	0.026	0.024	0.024	0.026	0.024	0.024
Biogas	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Wind	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056

Table 10
Optimized RE resource allocations (Supply is greater than Demand).

Villages	*Energy supply [kW h/year]*				*% of energy received*
	Solar	*Hydropower*	*Biomass*	*Wind*	
Silla (V1)	–	–	103,114	15,240	86.76% biomass, 12.82% Wind, 0.42% unmet demand
Nihaldanda (V2)	–	–	18,455	–	100% biomass
Dandagaon (V3)	–	–	16,252	–	100% biomass
Gawalidanda (V4)	–	–	19,164	–	100% biomass
Chifalti (Chiryali Danda) (V5)	–	–	20,405	–	100% biomass
Jaintwari (V6)	–	–	29,071	–	100% biomass
Talyakatal (V7)	–	–	34,879	–	100% biomass
Sandna laga Gawali Danda (V8)	–	–	43,234	–	100% biomass
Ragargaon (V9)	–	–	224,441	–	100% biomass
Airalgaon (V10)	–	–	43,696	–	100% biomass
Sera (V11)	–	22,775	88,670	–	20.44% Hydropower, 79.56% biomass
Kund (V12)	22,356	105,390	–	–	17.50% Solar, 82.50% Hydropower

Table 11
Comparison of results in [5] with the proposed transportation model.

Items	Optimization method		
	LINDO software 6.1 with EPDF 1.0 [5]	Transportation Algorithm	
Demand pattern	85% Demand	85% Demand	100% Demand
Optimal objective functions ($)	34,155.36	30,769.25	41,203.92
Hydropower (kW h/year)	115,465	128,165	128,165
Solar (kW h/year)	15,588	0	22,356
Wind (kW h/year)	12,201	0	15,240
Biomass (kW h/year)	543,546	558,332.4	641,381
Energy deficit (kW h/year)	0	0	0
Unit cost ($/kW h)	0.050	0.045	0.051

this type of resource optimization is regarded as unbalanced transportation problem. In this case, the amount of RE supplied (807,142 kW h/year) is lower than the actual demand required (807,644 kW h/year) but higher than the 15% reduced demand (686,497.4 kW h/year) as shown in Table 8. Table 9 shows the energy delivery cost in $/per kWh from energy sources to demand stations. A 10% increment in cost of delivering per kWh of energy to demand station is assumed if the region doesn't have the particular energy potential.

The optimization process for the villages is performed based on the proposed algorithm for unbalanced transportation problem. Table 10 shows the optimized RE resource allocation based on the actual demand for energy requirement. It is observed that Silla village (V1) have unmet demand of 0.42% with all villages receiving according to their demand.

The results obtained using transportation algorithm was compared with that of integrated renewable energy system (IRES) model developed in [5]. Table 11 shows that results of transportation algorithm for both actual demand and 15% reduced demand. As it is shown in the Table 11, the minimized total cost obtained using transportation algorithm depicts an improvement of 10.09% in cost. This has been also reflected in reduced average unit cost of delivery from 0.050 $/kW h to 0.045 $/kW h for the same amount of demand.

5. Conclusion

A transportation algorithm is proposed in order to optimize the resource allocations which minimize the overall cost while satisfying the demand and supply requirements. Three different cases were considered for the detail implementation of the model for renewable energy resource allocations. In all cases, the proposed transportation model is able to provide optimal solutions and could be used to evaluate various renewable energy options in order to meet the energy demand.

The results obtained using transportation model has been verified using similar papers in the area of integrated renewable energy system (IRES) models. It is noted that the minimized total cost obtained using transportation algorithm depicts an improvement of 10.09% reduction in cost over IRES model optimized using LINDO software 6.1.

The proposed model could be used as decision making tool in determining the types of renewable energy resources to be applied and the locations of the development of renewable energy resources.

References

[1] A. Gado, A. El-Zeftawy. Design and economy of renewable energy sources to supply isolated loads at rural and remoate areas of Egypt. In: Proceedings of the 20th International Conference and Exhibition on Electricity Distribution – Part 1 (CIRED 2009); 2009, p. 1.
[2] P.K. Katti, M.K. Khedkar. Towards sustainable energy systems: integrating renewable energy sources is the key for rural area power supply. In: Proceedings

of the 7th International Power Engineering Conference (IPEC 2005); 2005, p. 1.
[3] Wang J-J, Jing Y-Y, Zhang C-F, Zhao J-H. Review on multi-criteria decision analysis aid in sustainable energy decision-making. Renew Sustain Energy Rev 2009;13:2263.
[4] Bernal-Agustín JL, Dufo-López R. Simulation and optimization of stand-alone hybrid renewable energy systems. Renew Sustain Energy Rev 2009;13:2111.
[5] Akella AK, Sharma MP, Saini RP. Optimum utilization of renewable energy sources in remote area. Renew Sustain Energy Rev 2007;11:894.
[6] Moura PS, de Almeida Aníbal T. Multi-objective optimization of a mixed renewable system with demand-side management. Renew Sustain Energy Rev 2010;14:1461.
[7] Omu A, Choudhary R, Boies A. Distributed energy resource system optimisation using mixed integer linear programming. Energy Policy 2013;61:249.
[8] Fuso Nerini F, Howells M, Bazilian M, Gomez MF. Rural electrification options in the Brazilian Amazon: a multi-criteria analysis. Energy Sustain Dev 2014;20:36.
[9] Ashouri A, Fux SS, Benz MJ, Guzzella L. Optimal design and operation of building services using mixed-integer linear programming techniques. Energy 2013;59:365.
[10] Xydis G, Koroneos C. A linear programming approach for the optimal planning of a future energy system. Potential contribution of energy recovery from municipal solid wastes. Renew Sustain Energy Rev 2012;16:369.
[11] Jain BC. Rural energy centres based on renewables – case study on an effective and viable alternative. IEEE Trans Energy Convers 1987;EC-2:329.
[12] Mahapatra S, Dasappa S. Rural electrification: optimising the choice between decentralised renewable energy sources and grid extension. Energy Sustain Dev 2012;16:146.
[13] Agarwal N, Varun Kumar A. Optimization of grid independent hybrid PV–diesel–battery system for power generation in remote villages of Uttar Pradesh, India. Energy Sustain Dev 2013;17:210.
[14] Gupta A, Saini RP, Sharma MP. Hybrid energy system for remote area – an action plan for cost effective power generation. Ind Inf Syst 2008;2008:1.
[15] A. Gupta, R.P. Saini, M.P. Sharma. Modelling of hybrid energy system for off grid electrification of clusters of villages power electronics. In: Proceedings of the nternational Conference on Power Electronics, Drives and Energy Systems (PEDES '06); 2006, p. 1.
[16] A. Gupta, R.P. Saini, M.P. Sharma. Steady-state modelling of hybrid energy system. In: Proceedings of the Third International Conference on Electrical Engineering (ICEE'09); 2009, p. 1.
[17] Sharafi M, Elmekkawy TY. Multi-objective optimal design of hybrid renewable energy systems using PSO-simulation based approach. Renew Energy 2014;68:67.
[18] K. Balasubramanian, A. Cellatoglu. Optimal utilization of renewable energy resources in north cyprus: a proposed model. In: Proceedings of the Second International Conference on Computer and Electrical Engineering (ICCEE'09); 2009, p. 178.
[19] Iniyan S, Sumathy K. An optimal renewable energy model for various end-uses. Energy 2000;25:563.
[20] Alarcon-Rodriguez A, Ault G, Galloway S. Multi-objective planning of distributed energy resources: a review of the state-of-the-art. Renew Sustain Energy Rev 2010;14:1353.
[21] Omun A, Choudhary Ruchi, Boies Adam. Distributed energy resource system optimisation using mixed integer linear programming. Energy Policy 2013;61:249.
[22] Buoro D, Casisi M, De Nardi A, Pinamonti P, Reini M. Multicriteria optimization of a distributed energy supply system for an industrial area. Energy 2013;58:128.
[23] Chaouachi A, Andoulsi MR, Nagasaka R, Multiobjective K. Intelligent Energy Management for a Microgrid. IEEE Trans Ind Electron 2013;60:1688.
[24] Hochloff P, Braun M. Optimizing biogas plants with excess power unit and storage capacity in electricity and control reserve markets. Biomass Bioenergy 2014;65:125.
[25] Yao R, Steemers K. A method of formulating energy load profile for domestic buildings in the UK. Energy Build 2004;37(2005):663.
[26] P. Kadurek, W.L. Kling, P.F. Ribeiro, J.F.G. Cobben. Electricity demand characterization for analyzing residential LV distribution networks. In: Proceedings of 2013 IEEE Grenoble PowerTech (POWERTECH); 2013, p. 1.
[27] Azhari AW, Sopian K, Zaharim A, Ghoul MA. A new approach for predicting solar radiation in tropical environment using satellite images – case study of Malaysia. WSEAS Trans Environ Dev 2008:373.
[28] Study on Renewable Energy Resources. Authority for Electricity Regulation of Oman; 2008.
[29] Markvar T. Solar electricity. 2nd ed.. Chichester, England: John Wiley & Sons; 2000.
[30] Patel MR. Wind and solar power systems.Boca Raton, Florida: CRC Press; 1999.
[31] Exell RHB, Fook CT. The wind energy potential of Malaysia. Solar Energy 1986;36:281.
[32] RETscreen. Clean Energy project Analysis: RETscreen Engineering and Cases Textbook, Ministry of National Resouces Canada; 2005.
[33] Ong HC, Mahlia TMI, Masjuki HH. A review on energy scenario and sustainable energy in Malaysia. Renew Sustain Energy Rev 2011;15:639.
[34] World Development Indicators: Agricultural Inputs. In: W.B. Group, editor; 2015.
[35] Shuit SH, Tan KT, Lee KT, Kamaruddin AH. Oil palm biomass as a sustainable energy source: a Malaysian case study. Energy 2009;34:1225.
[36] Antunes CH, Gomes Á. Operational research models and methods in the energy sector. Eur J Op Res 2009;197:997.
[37] Ostergaard PA. Reviewing optimization criteria for energy systems analyses of renewable energy integration. Energy 2009;34:1236.
[38] Hamedi M, Zanjirani Farahani R, Husseini MM, Esmaeilian GR. A distribution planning model for natural gas supply chain: a case study. Energy Policy 2009;37:799.
[39] Blumenfeld D. Operations research calculations.Boca Raton, Florida: CRC Press LLC; 2001.
[40] Woldeyohannes AD, Woldemichael DE, Ing LC, Ru EZ. Transportation algorithm for optimizing renewable energy resources utilization at rural areas. Appl Mech Mater 2014;699:853.
[41] Renewable energy development & feed-in Tariff in Malaysia. available from: 〈http://investpenang.gov.my/portal/pdf/FiT_Ms_Chen_SEDA.pdf〉; 2011.