Economic evaluation of a hybrid renewable energy system (HRES) using hybrid optimization model for electric renewable (HOMER) software—a case study of rural India

Kamal Kant Sharma¹, Akhil Gupta², Raman Kumar³, Jasgurpreet Singh Chohan³, Shubham Sharma⁴, J Singh⁴, Nima Khalilpoor⁵,*, Alibek Issakhov⁶, Somnath Chattopadhyaya⁷ and Shashi Prakash Dwivedi⁸

¹Department of Electrical Engineering, Chandigarh University, Mohali, 140413, Punjab, India; ²Department of Electrical Engineering, IK Gujral Punjab Technical University, Batala Campus, Gurdaspur, 143506, Punjab, India; ³Department of Mechanical Engineering, Chandigarh University, Mohali, 140413, Punjab, India; ⁴Department of Mechanical Engineering, IK Gujral Punjab Technical University, Main Campus, Kapurthala, 144603, Punjab, India; ⁵Department of Energy Engineering, Graduate School of the Environment and Energy, Science and Research Branch, Islamic Azad University, Tehran, Iran; ⁶Faculty of Mechanics and Mathematics, Department of Mathematical and Computer Modelling, Al-Farabi Kazakh National University, Almaty, Kazakhstan; ⁷Department of Mechanical Engineering, Indian Institute of Technology (Indian School of Mines), Dhanbad, 826004, Jharkhand, India; ⁸Department of Mechanical Engineering, G.L. Bajaj Institute of Technology and Management, Greater Noida 201308, India

Abstract

This paper unveils a sustainable energy plan for optimal utilization of available electrical energy resources for an energy-deficient village. The chosen village is Nangal, near Barnala, Punjab, India. Primarily, the requirements of electric energy are recorded and elaborated for around 450 households. Aiming this, the potential to harness electric power and its effective utilization has been identified from the available resources of energy: biomass, agriculture waste and solar photovoltaic (PV) technology. In order to achieve this, a hybrid renewable energy system (HRES) model is proposed whose performance is evaluated by implementing it in hybrid optimization model for electric renewable (HOMER) software. HOMER software provides optimal solution for a commercial biogas plant for catering cooking gas demand. Also, a coordinated solution for solar PV-operated water pumps used for irrigation, village water supply and solar PV street lights is presented and analyzed. In this way, the accurateness of proposed model is investigated by estimating the optimal electric power demand and its economic benefits. It has been revealed that the computed cost of energy and total net present cost are $0.032/KWh and $76,837, respectively, by the parametric assessment of proposed HRES system. It is envisaged that the proposed model can be a road map for future research engineers in designing an effective energy utilization for villages.

Keywords: energy; biomass; photovoltaic; rural electrification; HOMER; water pump

*Corresponding author: nimakhalilpoor@gmail.com

Received 8 October 2020; revised 16 January 2021; editorial decision 28 January 2021; accepted 28 January 2021
1. INTRODUCTION

In recent decades, India is the third largest consumer of electricity across globe. Majorly, its gross domestic product is shared by power sector in making it a self-reliant economy. In recent times, India is poised to build a reliable and provide a cost-effective ecosystem in the future by the optimal utilization of its resources of renewable energy. However, it has also been revealed that the overall production of electric energy in India may not able to fulfill its emerging needs [1] for commercial and domestic end users. The uses of renewable energy resources have provided the optimum solutions to make all villages electrified and self-sustained in their energy requirements. Geographically, long ago, India has abundant natural resources of solar photovoltaic (PV) energy, animal wastes and crop residues. The energy yield is possible through these sources [2–4] available in rural areas and can be harnessed in an efficient way for catering energy demand. Some of the researchers have proven that these natural resources can be used to generate the electric energy to enhance the living standards of the villagers, thereby providing clean energy and reducing the burden on conventional grid [5–6]. It leads to significant reduction in fuel consumption. Especially, the uses of crop residues for electricity generation not only mitigates the problem of poor quality issues but also resists the practice of burning crop residue in open fields. These practices are harmful in producing emissions of significant amounts of green-house gases and matter of dispersed nature [2]. These gases generate risk to human health and reduce soil fertility.

To formulate a sustainable plan, an analysis is presented on the current utilization of village energy resources to supply clean energy [7–9]. Biomass is a term indicating degradation of biomass material with aerobic and anaerobic combustions. Solar PV energy plays an important role in its decomposition [10–13]. Biomass material incorporates different types of vegetation grown in wet and dry lands (land and water based), waste biomass, sewage, agriculture residues, animal wastes and few industrial wastes [3]. Further, it is classified as woody and non-woody biomass. Agricultural residues, waste from cattle and poultry are biodegradable in nature and are collectively constitute non-woody biomass. Agricultural residues can be categorized as crop residues and agro-industrial residues. On the other hand, the agro-industrial residue comprises the by-products of post-harvest processing of crops. Such processing includes cleaning, threshing, sieving and crushing [2].

Importantly, the amounts of agricultural residues produced vary from crop to crop. The other factors like soil types, seasons and irrigation conditions determine the amount of agriculture residues produced. These factors are directly related to crop production and the ratio mix among main crops [14,15]. Hence, for a given amount of crop production, the amount of agriculture residue can be estimated by its residue ratio. The cultivable area and the biomass yield of any residue from crop are obtained by averaging the yield of previous years [16–18]. Besides primary data collection, the consumption of biomass through direct interaction with the villagers is collected. The estimation of residue generation is made by using residue production ratio (RPR). RPR is computed by direct measurements in fields. Air dried residue product ratio for some crops is also available and can be used for RPR estimation. Therefore, this paper aims to devise a feasible electric energy consumption plan for the chosen village and meeting its domestic energy requirements by using available renewable energy sources [19]. The ultimate objectives of present study are to propose an optimal solution in energy consumption for the Nangal village using hybrid optimization model for electric renewable (HOMER) software. Overall objectives of the present study are presented as follows:

i. To study the existing energy consumption, identify the available energy resources and carry out electrical load assessment.

ii. To develop a hybrid energy system model and implement it in HOMER software to generate a cost-effective solution with uninterrupted availability of cheap and good quality of electric power.

Aiming this, the paper presents a hybrid solar PV/biomass-based energy consumption model. The main difference of the proposed model from the erstwhile models is its application in optimization-based HOMER software. Section 1 presents the introduction. Section 2 presents the assessment of domestic load requirements and its potential in optimal usage of existing available energy resources. Especially, a hybrid renewable energy system (HRES) is modelled for supplying electricity requirement and plans to meet other energy needs of Nangal village, Punjab, India, are discussed. Energy consumption patterns are studied and analysed. Section 3 highlights the implementation of proposed HRES into HOMER software [4]. Net present cost (NPC) algorithm implemented in HOMER software according to which cost of energy (COE) is estimated for the proposed system. Section 4 presents the results and discussion. It is revealed that the coordination of solar PV module and a biomass plant is capable to cater the variable electric power requirements of the proposed village. In addition, the proposed hybrid model is capable to generate and supply cheap electric power with good quality to the connected load. An effective cost analysis is presented for the proposed plan with its benefits. Section 5 presents the conclusion of the work. It is envisaged that the proposed HRES model is capable to provide an optimal cost-effective solution by the coordination of both solar PV and biomass technology. The model is further extendable to grid side applications in power quality estimations for the future research engineers.

2. LOAD ESTIMATIONS—A BASIC SURVEY

To fulfill the timely electricity demand in Nangal village, the surveying assessment of connected loads is examined through the optimal use of biomass energy and solar PV technology. The connected load mainly covers compact fluorescent lamps, fluorescent tubes, ceiling fans, coolers and television sets. Mainly, energy consumption data collected for Nangal village near Barnala, Punjab, India have been summarized in Table 1. It has been revealed
that the nature of domestic load varies intermittently in different seasons [20,21]. In other words, this seasonal variation leads to dynamic changes in energy requirements of the domestic sector. Addressing this, a case study is presented for two seasons: April to October and November to March, comprising summer season and winter season, respectively. The data have been summarized in Table 2 for both seasons. Majorly, hourly basis demand of chosen village is considered as an input to HOMER software [4]. From the basic simulations performed, it has been found that the average energy consumption of the chosen village is 510 kWh/day, with 7 kW peak connected load. The data for air dry weight of residue per tonne of crop produced have been summarized in Table 3.

It is especially envisaged in [5] that the electric power demand of connected loads is catered by using biomass and solar PV-based HRES model. In view of this importance, a Simulink model for HRES is developed to determine an optimal solution that can extract maximum useful power from the available resources at Nangal village location. The optimal solution is obtained by implementing proposed HRES model in HOMER software. The proposed hybrid model meets electricity requirements and validates its economic feasibility. Importantly, HOMER energy software implemented at an identified off-grid village location in Punjab undertakes the study of simulation-based architecture to derive an accurate and cost-effective solution. The domestic load and its yearly profile for the Nangal village in summer season on daily basis are depicted in Figure 1a and Figure 1b, respectively. Notably, the maximum consumption of connected load of around 45 kW takes place between 6 pm to 7 pm. Also, the maximum consumption of the connected load of 75 kW takes place in January; however, the mean value patterns of connected load indicate that the consumption of 20 kW is sufficient to balance the electric power demand of natives living in the village.

Importantly, India is bestowed with ample resources of energy for generating cheap and good quality electric power. Among these, the most inexhaustible, clean and abundant resource is solar PV energy. It has been observed that the total amount of energy consumption has been less than the energy intercepted by the Earth from the Sun [22]. Therefore, in this work, it is proposed to harness freely available electric power by installing solar PV modules. For the present study, the electric power required to operate water pumps is harnessed by connecting solar PV modules of 1800 Wp capacity. It also meets irrigation and water supply demand. Motor pump sets of 2-HP capacity are of DC centrifugal mono-block type operated at 60 V DC nominal operating voltage. Maximum suction and dynamic heads are 7 m and 10 m, respectively. Bore well size is of 150 mm diameter.

For efficient solar PV installations, it is estimated that required shadow free area is 100 m². Water pumps are available in 4-HP rating for installation. However, it is recommended that such solar PV-operated water pumping systems are of optimal use for small farmers and can replace diesel-operated water pump sets. Notably, such solar PV-operated water pumps can discharge up to 1 200 000 to 1 400 000 litres of water and are sufficient for irrigating 1.6–2 hectares of agricultural land. Major benefits of operating water pumping systems through solar PV modules are as follows: saving of coal, reduced diesel consumption, long life, more reliability with trouble free performance, less maintenance and environmentally friendly. Consequently, the successful implementation of solar PV-operated water pumping system is depicted in Figure 2.

3. IMPLEMENTATION OF HYBRID RENEWABLE ENERGY SYSTEMS

As illustrated in Figure 3, the proposed HRES model is mainly composed of a conventional electric power generator, a biomass generator model S460, a solar PV module and DC/AC buck-boost converter systems for a 71-kW domestic connected load [6,7]. HOMER software is capable to compute optimal cost and required size of each type of energy source. Notably, NPC has been computed for various combinations to derive most optimized solution [23–26]. In order to achieve this, the proposed system is simulated with energy consumption load of 510 kWh/day, with 95% of lightning load. In addition, the proposed system has an intermittent load factor and an annual peak load of 71 kW. In general, the coordinated control of a solar PV module, a bio-waste generator, a battery and buck-boost converters at a specified load have been successfully implemented.

4. OPTIMIZATION RESULTS AND DISCUSSION

In this work, the main components of proposed HRES model are segregated biomass, a 2-HP water pump and a solar PV module. The overall objective of the proposed model is to derive the optimal solution for electric power demand of the chosen village of Nangal through its available renewable energy resources. Therefore, an important task for rural electrification has been performed for making the chosen village of Nangal village self-reliant in its energy demand [5]. In addition, the proposed HRES model is capable to justify the size and pricing of each energy generating unit, which integrates their operational features to

| Table 1. Geographical data of village Nangal. |
|-----------------------------------------------|
| Name of the village | Nangal |
| District, state     | Barnala, Punjab |
| Location            | 30°24’52.31”N latitude and 75°36’27.77”E longitude |
| Total number of households | 450 |
| Population          | 3500 |
| Major occupation    | Farming |
| Total area          | 1754 hectare |
| Main crops          | Paddy/wheat |
| Cultivable area     | 1650 hectare |
Table 2. Domestic load and energy consumption pattern of village Nangal.

| Appliance              | Power capacity (W) | Number of devices | Average hours per day | Energy consumption (kWh/day) |   |
|------------------------|--------------------|-------------------|-----------------------|------------------------------|---|
|                        |                    |                   | Summer                | Winter                       |   |
| Compact fluorescent lamp | 20                 | 1350              | 8                     | 9                            | 216 | 243 |
| Fluorescent tube       | 40                 | 900               | 4                     | 6                            | 144 | 216 |
| Cooler                 | 120                | 450               | 12                    | 0                            | 1080| 0   |
| Fan                    | 50                 | 1800              | 12                    | 0                            | 1296| 0   |
| Television             | 100                | 450               | 12                    | 12                           | 450 | 54  |
| Total                  |                    |                   | 46                    | 27                           | 3186| 513 |

Figure 1. Domestic load profile (a) on daily basis and (b) yearly basis, in summer season.

Figure 2. Installation of a solar PV-operated water pump at the village of Nangal, Barnala.

Table 3. Dry air weight of residue per tonne of residue.

| Name of crop | Type of residue | RPR   |
|--------------|----------------|-------|
| Rice paddy   | Straw          | 0.45–2.9 |
|              | Husk           | 0.22–0.5 |
| Wheat        | Straw          | 0.7–1.8  |

achieve sustainability. Adding to this, a multilayer artificial neural network coordinated with neuro-fuzzy inference system and least squares support vector machine has been examined in reference [27–29]. Sensitivity analysis is performed to model each factor of its output. It has been revealed that the proposed model can be implemented for heat transfer-based applications in the presence of nanofluids. Also, various machine learning techniques like R-squared and root mean square error to study the sensitivity
Economic evaluation of an HRES using HOMER software

Figure 3. Simulink schematic of a hybrid renewable energy system.

Table 4. Monthly averages of clearness index and daily radiations.

| Month    | Clearness index | Daily radiation (kWh/m²/day) |
|----------|-----------------|------------------------------|
| January  | 0.593           | 3.464                        |
| February | 0.604           | 4.281                        |
| March    | 0.607           | 5.294                        |
| April    | 0.617           | 6.296                        |
| May      | 0.617           | 6.859                        |
| June     | 0.602           | 6.882                        |
| July     | 0.508           | 5.704                        |
| August   | 0.514           | 5.395                        |
| September| 0.608           | 5.558                        |
| October  | 0.651           | 4.916                        |
| November | 0.634           | 3.873                        |
| December | 0.573           | 3.123                        |
| Average  | 0.590           | 5.141                        |

analysis are presented and discussed in [30–32]. The most significant relevancy factor is determined for the solar PV systems. The optimization of HRES model has been carried in HOMER software.

To ensure the fair evaluation, the solar radiation data have been taken at 30°24’52.31”N latitude and 75°36’27.77”E longitude for the Nangal village, Punjab, India. For brevity only, the data have been generated using HOMER software from solar energy web portal of the National Aeronautical Space Agency. These data, which mainly include average daily solar radiation in kWh/m²/day, are summarized in Table 4. Also, monthly solar radiations for the whole year at selected site are presented in Figure 4 with an annual average of 5.141 kWh/m²/day. According to optimization results presented in Figure 5a, it is evident that the NPC of $75 817 is the optimal solution using a biomass generator. From Figure 5b, it is also evident that the hybrid energy system comprising 0.5 kW solar PV array, 40 kW biomass generator, 35 kW converter and 40 batteries is the proven feasible solution. The computed COE and total NPC are computed as $0.032/kWh and $76 837, respectively.

Biogas production has been an efficient way to meet the increasing cooking gas demand. Therefore, the sanitation in village can be improved by linking sanitary toilets with biogas plants. Notably, the slurry as by product is used as a fertilizer that can be returned to soil. The installation design of the bio-gas plant mainly depends on average population of cattle and the amount of available dung. The size of a plant, cattle dung available and estimated cost are summarized in Table 5. The survey of the said village revealed that each household owned ~2–3 cattle heads on an average of ~10 heads for three houses; therefore, a 6–8 cubic meter size biogas plant for three houses is proposed to meet the cooking gas demand.

4.1. Economic analysis

For the effective implementation of HRES, the proposed configuration has been modelled in HOMER software. Specifications chosen are 0.5 kW solar PV array, 40 kW biomass generators and 35 kW converters with 40 batteries. Typical specifications are illustrated in Table 6. It is revealed that the computed COE and total NPC are $0.032 per kWh and $76 837, respectively, for the proposed system.

Table 5. Cost analysis for biomass input.

| Quantity of daily cattle dung | Number of cattle heads | Estimated cost ($) |
|------------------------------|------------------------|--------------------|
| 25 kg                        | 2–3                    | 102.85             |
| 50 kg                        | 4–6                    | 128.57             |
| 75 kg                        | 7–9                    | 154.28             |
| 100 kg                       | 10–12                  | 171.42             |
| 150 kg                       | 14–16                  | 192.85             |

Table 6. System report of HRES.

| Name of device | Specification chosen |
|----------------|----------------------|
| SPV array      | 0.5 kW               |
| Biomass generator | 40 kW               |
| Battery        | S460                 |
| Inverter       | 35 kW                |
| Rectifier      | 35 kW                |
| Dispatch strategy | Cycle charging      |
Real power generated from the coordinated effort of solar PV modules and a biomass generator has been shown in Figure 6. It is evident that a maximum power of 40 kW (shown by black line) is possible to generate through biomass generator. In addition, the inverter output power generates the maximum real output power of 15 kW. Thus, it is clear that proposed HRES system is capable to cater the real power requirement of AC primary connected load (shown by blue line).

Recently, the Government of Punjab, India, has started offering various incentive schemes promoting implementation of renewable energy resources, especially in the rural sector. Notably, Punjab, being an agrarian state, has numerous promotion offers for the generation of electric power-based renewable energy resources [33–35]. Among these, mainly 40% subsidy on solar PV-operated irrigation pumps is available to promote state flagship program of agriculture diversification. In another remarkable scheme, an amount of $6 940 445 was sanctioned for ensuring the availability of subsidized solar PV-operated water pump systems to farmers, fruit and vegetable growers. Thus, on an average, $3473 is spent to install a solar PV-operated irrigation pump [36]. Out of these, 40% subsidy ($1389) is given by state government and 30% ($1042) by Union government India. The expenditure on remaining amount is to be borne by the beneficiary. The details of cost involved in the installation of solar PV-operated water pumping system are summarized in Table 7. In this way, both state and central governments are promoting the use of renewable-based electric power to operate electric water pumps. This option can eliminate the comparatively expensive diesel pumps that are currently used in the fields.

4.2. Economic impact

At present, liquefied petroleum gas (LPG) filled cylinders and firewood are the main source for catering electric energy demand for cooking. This option has not been found to be healthy and efficient. Therefore, it is proposed that the energy requirements in cooking are fulfilled by proper utilization of available manure through domestic biogas plant. The estimation of the payback period by installing a biogas plant is presented as follows:

Cost of proposed biogas plant of 6 cubic meter size for four houses = $259.
Cost of proposed biogas plant for single house = $259/4 = $64.75. Estimated cost of using LPG cylinder per month by a single household = $7.24. Therefore, payback period of a biogas plant = $64.75/$7.24 = 9 months (depicted in Figure 7).

In addition, it is proposed that solar street lighting is an ideal choice for lighting the village streets due to their minimum maintenance. The specification of one of the available solar lights is given in Table 8. The system is provided with battery storage backup sufficient to operate the light for 10–11 hours daily during nights. Estimated cost of each solar light is $294 each. The village is proposed with 20 street lights with total cost of $5880. The total estimated plan of proposed HRES is estimated as $90 256 (see Table 9). It has also been reported in [37] that wood waste has the lowest NPC and COE with $247 686 and $0.182/kWh under charge cycle control, respectively. In addition, the results obtained through sensitivity studies have shown that the PV/hydrokinetic turbines/biomass gasifiers/batteries system fuelled by wood waste has an increase in NPC and COE if the minimum value of state of charge of the batteries increases. The greatest increase has been presented by the load following control, the NPC has increased by $170 000 and the COE by $0.17/kWh. In the present research, furthermore, solar PV modules having installed capacity of 1800 Wp capacity are recommended for operating connected water pumps. From the comprehensive cost analysis, it has been found that the NPC of $75 817 is the optimal solution for a proposed biomass generator. The computed COE and total NPC is computed as $0.032/kWh and $76 837, respectively, for the proposed system. Finally, the feasibility of major cost savings is justified by installation of solar PV operated for 2-HP water pumps. Overall, the accurateness of HOMER software is sufficient to demonstrate the optimized solution for variable electricity requirements and validating economic feasibility.

5. CONCLUSIONS

In the present research work, an effort has been made for by developing a hybridized type biomass and solar PV coordinated model at the chosen village of Nangal, Punjab, India. The proposed HRES model is developed for 450 households having farming as major occupation and implemented in HOMER software for optimization. After the assessment of electric energy requirements, it is revealed that a 6–8 cm$^3$ size biogas plant for three houses is sufficient to cater the demand of cooking gas. In addition, it is also observed that the average energy consumption of the village is 510 kWh/day at 7 kW peak load. Furthermore, solar PV modules having installed capacity of 1800 Wp capacity are recommended for operating connected water pumps. From the comprehensive cost analysis, it is revealed that that NPC of $75 817 is the optimal solution for a proposed biomass generator. The computed COE and total NPC is computed as $0.032/kWh and $76 837, respectively, for the proposed system. Finally, the feasibility of major cost savings is justified by installation of solar PV operated for 2-HP water pumps. Overall, the accurateness of HOMER software is sufficient to demonstrate the optimized solution for variable electricity requirements and validating economic feasibility.

REFERENCES

[1] Chen YD, Ho SH, Nagarajan D et al. Waste biorefineries—integrating anaerobic digestion and microalgae cultivation for bioenergy production. Curr Opin Biotechnol 2018;50:101–10.

[2] Abraham A, Mathew AK, Sindhu R et al. Potential of rice straw for bio-refining: an overview. Bioresour Technol 2016;215:29–36.
Xie H, Zheng S, Ni M. Microgrid development in China: a method for renewable energy systems for electric power generation: configurations, control, and applications. IEEE Trans Sustain Energy 2011;2:392–403.

Huasine. Mathematical models of the kinetics of anaerobic digestion—a selected review. Biomass Bioenergy 1998;14:561–71.

Yadav DK, Girimaji SP, Bhatti TS. Optimum hybrid power system design for rural electrification. In Proceedings of 2nd IEEE International Conference on the Power, Control and Embedded Systems, 2012. India: Allahabad. 977–1013.

Emad D, Hameed MAE, Yousef MT et al. Computational methods for optimal planning of hybrid renewable microgrids: a comprehensive review and challenges. Arch Comput Method Eng 2020;27:1297–319.

Ramakumar R, Abouzahr I, Ashenayi K. A knowledge-based approach to the design of integrated renewable energy systems. IEEE Trans Energy Convers 1992;7:648–59.

Sefeedpari P, Vellinga T, Rafaei S et al. Technical, environmental and cost-benefit assessment of manure management chain: a case study of large-scale dairy farming. J Clean Prod 2019;233:857–68.

Khatod DK, Pant V, Sharma J. Analytical approach for well-being assessment of small autonomous power systems with solar and wind energy sources. IEEE Trans Energy Convers 2010;25:535–45.

Klein BC, Bonomi A, Filho RM. Integration of microalgae production with industrial biofuel facilities: a critical review. Renew Sust Energ Rev 2018;82:1376–92.

Poblete IB, Araujo ODQF, Medeiros JLD. Dynamic analysis of sustainable biogas-combined-cycle plant: time-varying demand and bioenergy with carbon capture and storage. Renew Sust Energ Rev 2020;131:109997.

Roy RB. Design and performance analysis of the solar PV DC water pumping system. Can J Electr Electron Eng 2012;3:403–12.

Ministry of New and Renewable Energy. MNRE website: http://mnre.gov.in.

Xie H, Zheng S, Ni M. Microgrid development in China: a method for renewable energy and energy storage capacity configuration in a megawatt-level isolated microgrid. IEEE Electrifaction Mag 2017;5:28–35.

Mariani RR, Sarenì B, Roboam X. Integrated optimal design of a smart microgrid with storage. IEEE Trans Smart Grid 2017;8:1762–70.

Crandaill MS, Adams DM, Montgomery CA et al. The potential rural development impacts of utilizing non-merchantable forest biomass. For Policy Econ 2017;74:20–9.

Heidari A et al. A comprehensive review of renewable energy resources for electricity generation in Australia. Front Energy. 2020;14:510–29.

Tripathi L, Mishra AK, Dubey AK et al. Renewable energy: an overview on its contribution in current energy scenario of India. Renew Sust Energ Rev 2016;60:226–33.

Porco C. Time-dependent climate impact of production and use of wood pellets from short rotation forestry and logging residues. Dissertation for the Doctoral Degree. Uppsala: Swedish University of Agricultural Sciences, 2017.

Hammar T. Climate impacts of woody biomass use for heat and power production in Sweden. Dissertation for the Doctoral Degree. Suecia: Acta Universitatis agriculturae, 2017.

Haberl H, Beringer T, Bhattacharya SC et al. The global technical potential of bio-energy in 2050 considering sustainability constraints. Carr Open Environ Sustain 2010;2:394–403.

Luo X, Wang J, Dooner M et al. Overview of current development in electrical energy storage technologies and the application potential in power system operation. Appl Energy 2015;137:511–36.

Kichonge B, Mikilaha ISN, John GR et al. The economics of renewable energy sources into electricity generation in Tanzania. J Energy 2016;5837154.

Poompavai T, Kowsalya M. Control and energy management strategies applied for solar photovoltaic and wind energy fed water pumping system: a review. Renew Sust Energ Rev 2019;107:108–22.

Singh B, Kumar R. Solar photovoltaic array fed water pump driven by brushless DC motor using landsman converter. IET Renew Power Gener 2016;10:474–84.

Baghban A, Mostafa K, Mohammad AN et al. Sensitivity analysis and application of machine learning methods to predict the heat transfer performance of CNT/water nanofluid flows through coils. Int J Heat Mass Transf 2019;128:825–35.

Baghban A, Ali J, Mojtaba S et al. Developing an ANFIS-based swarm concept model for estimating the relative viscosity of nanofluids. Eng Appl Comput Fluid Mech 2019;13:26–39.

Mohammad HA, Baghban A, Milad S et al. Evolving connectionist approaches to compute thermal conductivity of TiO$_2$/water nanofluid. Phys A Stat Mech Appl 2020;540:122489.

Mohammad HA, Baghban A, Mahyar G et al. An insight into the prediction of TiO$_2$/water nanofluid viscosity through intelligence schemes. J Therm Anal Calorim 2020;139:2381–94.

Mohammad HA, Baghban A, Milad S et al. Evaluation of electrical efficiency of photovoltaic thermal solar collector. Eng Appl Comput Fluid Mech 2020;14:545–65.

Baghban A, Jafar S, Fatollah P et al. Towards experimental and modeling study of heat transfer performance of water-SiO$_2$ nanofluid in quadrangular cross-section channels. Eng Appl Comput Fluid Mech 2019;13:453–69.

Normyle A, Pittock J. A review of the impacts of pumped hydro energy storage construction on subalpine and alpine biodiversity: lessons for the snowly mountains pumped hydro expansion project. Aust Geogr 2020;51:53–68.

Ouchanis I, Rabbi A, Yahyaoui I et al. Renewable energy management algorithm for a water pumping system. Energy Proc 2016;111:1030–9.

Li Z, Ma L, Li Z et al. Multi-energy cooperative utilization business models: A case study of the solar-heat pump water heater. Renew Sust Energ Rev 2019;108:392–7.

Cross N, Gaunt C.T. Application of rural residential hourly load curve in energy modelling. In: Proceedings of IEEE Power Technology Conference, 2003, Bologna, Italy, 3. 10.1109/PTC.2003.1304492.

Antonio C, Paul A, Francisco J. Energy analysis and techno-economic assessment of a hybrid PV/HKT/BAT system using biomass gasifier: Cuenca-Ecuador case study. Energy 2020;202:117727.