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There are several other models such as the one developed by Ayub et al. Song et al. By the simulation results, the thermal efficiency of the coupled system is Various articles described only the solar-geothermal ORC system for the thermal efficiency performance.

There is not any literature which describes the potential of hot spring for power generation by the ORC technology. When the hot spring is coupled with a solar thermal collector, the temperature of the hot spring will be increased.

This increase in temperature is enough to operate the ORC system. Therefore, the current research could address the potential for power generation by hot springs where the source temperature is enough to operate the ORC plant in Nepalese context. The main objective of the research is to study the feasibility of electrical power generation by the concept of stand-alone hybrid solar-geothermal organic Rankine cycle ORC technology in the Bhurung Tatopani area of Myagdi District, Nepal.

In order to study the feasibility of stand-alone hybrid solar-geothermal ORC system technology, an experiment and thermodynamic models have been developed and proposed for characterizing the performances of the system.

Various methods that have been adopted in this study are as follows: In the preliminary geothermal hot spring site investigation, the following assessment had been conducted in Bhurung Tatopani. In the experimental analysis, the temperature of the hot spring was measured along with the flow rate. The hot spring water was stored in the storage tank.

The stored hot water temperature was measured for knowing whether the temperature could be able to run the ORC system or not. Furthermore, the duration of constant hot water temperature was measured throughout the two different seasons winter and summer.

The temperature of the stored hot water was measured. Later, the stored hot water was being mixed with hot spring. The measured temperature after mixing helped to estimate the capability for evaporation of the working fluid. The measured temperature was applied in the developed model. The built model predicts the power output from the hybrid stand-alone solar-geothermal ORC system.

Figure 2 shows the experimental setup for measuring the temperature. For the development of models, the desired thermodynamic properties of the ORC working fluid at different state points should be known.

The thermodynamic properties of an ORC working fluid can be described best by the energy equation and calculated using the software known as Energy Equation Solver EES. Therefore, all the thermodynamic properties of ORC working fluids in this study will be obtained using the academic approach.
The effect of thermal efficiency of the system changes with heat source temperature. The higher the heat source temperature, the higher the thermal efficiency. The rise in geothermal source temperature yields higher power output. This trend is presented in Figure 5. The maximum thermal efficiency of the system for the particular heat source temperature.

The ORC components in the system consist of a pump, an expander, an evaporator, and a condenser. The main governing equations for the development of the models are described below: where and denotes the pressure at the outlet and inlet of the pump, respectively. The abovementioned governing equations are based on basic laws of thermodynamics as presented by the authors [17].

The solar radiation data accounts for beam, diffuse, and reflected components of the solar irradiation. The model consists of computation of clear sky global irradiation on a horizontal surface and calculation of clear sky index, diffuse, and beam components on inclined surfaces. The solar collector can be modeled for two different types of collector. They are non-concentrating and concentrating collectors. The governing equation for the solar collector is as follows [18]:

\[
\eta_{solar} = \frac{N_{output}}{N_{input}}
\]

where \( N_{output} \) and \( N_{input} \) are the collector output and input power, respectively.

The net solar ORC efficiency of the system is given by the following equation: In another part of the research, the economic analysis for the hybrid system was conducted which included calculation of the net present value (NPV), payback period, internal rate of return (IRR), benefit-cost ratio (BC ratio), and levelised cost of electricity production (LCOE).

The techno-economic analysis of the hybrid solar-geothermal ORC has the governing equations which are shown in Table 1. The investigated site was on the location longitude: There are various hot springs in Nepal, but the Tatopani hot spring was one of the sites where the experimental work has been conducted.

The site had not been contaminated, and the location for experiment was perfect. There was no any debris near the site source of hot spring. During the months of February and March, the Kailugndaki River has not affected the heat source site, but the effect can be seen when it was rainy season during July.

It was observed that the hot spring was used as recreational purposes in that location. The hot spring was pumped from the source in the pond for the storage and recreational activities such as bathing and refreshing.

The nearby hot springs were quite far from the investigated location. This was the preliminary investigation before conducting the experiment in order to study the feasibility of the power generation by the geothermal source hot spring ORC system. After the preliminary investigation of the source of the hot spring in the location, the temperature of the hot spring was measured.

The data logger was used for measuring the temperature with thermocouples. The temperature of the source was almost constant through the measurement. Figure 3 shows the temperature profile of the hot spring on 31st October. The measured temperature was enough to observe the power output of the geothermal ORC system alone with two different organic working fluids Ra and Rfa by applying the obtained data on the developed model.

Furthermore, a series of experiment were carried out in order to find the maximum temperature of the hot spring when it was passed into the solar collector. This final temperature was again applied in the model in order to observe the performance of the system by simulation results with the organic working fluids. The model of the hybrid solar-geothermal ORC system consists of various main components such as pump, evaporator, expander, condenser, and solar field collector.

The various thermodynamic parameters that were used for simulation of the overall performance of the hybrid system are shown in Table 2. Based on these boundary conditions indicated in the table, the results for the system had been analyzed.

There are various factors that affect the performance of the system, and the results are presented in this section. The system efficiency is one of the most significant indexes for evaluating the characteristics and performance of the hybrid solar-geothermal ORC system technology.

Two working fluids Ra and Rfa had been taken for investigation of the system performance. Ra suits well for a low-temperature heat source whereas Rfa can be used for a medium-temperature heat source. The Carnot efficiency can be increased when the heat source temperature is increased and the temperature of the heat sink is lowered. Figure 4 shows the Carnot efficiency of the proposed hybrid solar-geothermal ORC system for the particular heat source temperature.

The effect of thermal efficiency of the system changes with heat source temperature. The higher the heat source temperature, the higher the thermal efficiency. The rise in geothermal source temperature yields higher power output. This trend is presented in Figure 5. The maximum thermal efficiency simulated was 8. Likewise, the net power output was found to be These performances on the thermal efficiency and net power output can be seen in Figure 6.
The highest dependency of NPV is for annual production of power followed by annual equivalent cost for both of the working fluids. The NPV from the hybrid solar-geothermal ORC system was examined and illustrated the importance of influencing parameters for making decision whether it is worth investing or not. The results of the sensitivity analysis can be observed from Table 8. Here, the payback period is only 5. In Figures 15 and 16, the maximum percentage of the share in the system is for the solar ORC unit. Due to high cost of the solar collector, this part is quite expensive as compared to solar PV.

In the present study, annual power production, annual equivalent cost, and interest rate have been chosen for the analysis. The specific cost per kW of the hybrid solar-geothermal ORC system has been estimated by taking the reference [20]. The cost of working fluids Rfa and Ra was taken on the basis of references [20]. Table 4 shows the total capital cost for the hybrid solar-geothermal ORC system. The maximum percentage of the share in the system is for the solar ORC unit. Due to high cost of the solar collector, this part is quiet expensive as compared to solar PV.

During the estimation of the economic index, the component cost and operation and maintenance cost have been taken into account. It is assumed that the installation of the hybrid system is completed within one year. The salvage value for the system after 20 years is assumed to be zero. Based on these assumptions, the economic indicators were presented. Rfa is quiet expensive as compared to other working fluids. Table 5 shows the capital cost, annual generation cost, and cost of electrical power generation for two different working fluids.

Another economic indicator is the payback period of the installed system. The payback period is the number of years needed for the return of the investment. The return of investment can be achieved after 10 years of power generation. It is seen from the analysis that the hybrid solar-geothermal ORC system can be economically feasible when the LCOE is doubled with the cost of electricity production. The same pattern is seen with the working fluid Rfa as presented in Figure 10. The solar collector area can be obtained according to the turbine inlet temperature. The system pressure ratio determines the pressure ratio of the system after simulation. The system pressure ratio is small, the size of the expander is small and compact.

The developed model of the hybrid solar-geothermal organic Rankine cycle system has been validated against the previous work of references indicated in Table 3. The results of the model are very closed and showed good agreement with the referenced work. This demonstrated that the developed model is viable for the system in this study. There are slight variations in the value obtained because several authors used different fluid property databases.

The techno-economic analysis was carried out in order to estimate the levelised cost of electricity generation by this technology. Furthermore, the economic indexes such as net present value NPV, payback period PB, internal rate of return IRR, and sensitivity analysis were estimated to find the details of economic importance for manufacturers, investors, stakeholders, and energy planners.

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should be positive in order to be feasibly invested. Figure 15 shows a slightly curvature type of profile; this is due to the negative NPV for the system.

The study reported the feasibility analysis of the stand-alone hybrid solar-geothermal organic Rankine cycle technology for power generation in Bhurung Tatopani, Myagdi. The experiment conducted on the Tatopani site revealed the temperature of the hot spring to be another experiment included feeding of the hot spring into the solar collector in order to observe the temperature increment which can be applied in the developed model.

The thermodynamic models were developed from the governing equations of ORC system components. The developed model predicted the performance of the system when the input parameters were given.

The power output from the system was It was concluded that the working fluid R134a could get higher power output due to its thermo-physical characteristics when subjected to various temperature values. In another part of the study, the techno-economic analysis was conducted for the hybrid system. The Payback period, benefit-cost ratio, and IRR are 12 years, 1. Therefore, the key finding is that the stand-alone hybrid solar-geothermal ORC system is feasible for power generation and is economically viable.

The data used to support the findings of this study are available from the corresponding author upon request. Suresh Baral. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. We will be providing unlimited waivers of publication charges for accepted articles related to COVID-19.

About Solar Organic Rankine Cycle Power System For Developing Countries Writer

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Therefore, the current research could address the potential for power generation by hot springs where the source temperature is enough to operate the ORC plant in Nepalese context.

The main objective of the research is to study the feasibility of electrical power generation by the concept of stand-alone hybrid solar-geothermal organic Rankine cycle ORC technology in the Bhurung Tatopani area of Myagdi District, Nepal. In order to study the feasibility of stand-alone hybrid solar-geothermal ORC system technology, an experiment and thermodynamic models have been developed and proposed for characterizing the performances of the system.

Various methods that have been adopted in this study are as follows: In the preliminary geothermal hot spring site investigation, the following assessment had been conducted in Bhurung Tatopani. In the experimental analysis, the temperature of the hot spring was measured along with the flow rate.

The hot spring water was stored in the storage tank. The stored hot water temperature was measured for knowing whether the temperature could be able to run the ORC system or not. Furthermore, the duration of constant hot water temperature was measured throughout the two different seasons winter and summer.

The temperature of the stored hot water was measured. Later, the stored hot water was being mixed with hot spring. The measured temperature after mixing helped to estimate the capability for evaporation of the working fluid. The measured temperature was applied in the developed model. The built model predicts the power output from the hybrid stand-alone solar-geothermal ORC system. Figure 2 shows the experimental setup for measuring the temperature. For the development of models, the desired thermodynamic properties of the ORC working fluid at different state points should be known.
The thermodynamic properties of an ORC working fluid can be described best by the energy equation and calculated using the software known as Energy Equation Solver EES. Therefore, all the thermodynamic properties of ORC working fluids in this study will be obtained using the academic version of the software EES. This information can be easily available in their websites. Moreover, the thermodynamic analysis in a steady state shall also be conducted for each thermal conversion unit and ORC unit.

Various assumptions for modeling are as follows: 1 The calculation is based on steady-state conditions 2 The pressure drops in the heat exchangers are neglected 3 The heat losses from the various components are assumed to be negligible. The general expressions for the energy balances of any steady state that are applied in each of the system components can be expressed as where subscripts i and o represent the inlet and outlet, respectively, and represent the mass flow rate and specific enthalpy, respectively, of the streams of the system working fluid, and and represent the heat transfer and work transfer crossing the component boundaries, respectively.

The ORC components in the system consist of a pump, an expander, an evaporator, and a condenser. The main governing equations for the development of the models are described below: where and denotes the pressure at the outlet and inlet of the pump, respectively. The abovementioned governing equations are based on basic laws of thermodynamics as presented by the authors [17].

The solar radiation data accounts for beam, diffuse, and reflected components of the solar irradiation. The model consists of computation of clear sky global irradiation on a horizontal surface and calculation of clear sky index, diffuse, and beam components on inclined surfaces. The solar collector can be modeled for two different types of collector. They are non-concentrating and concentrating collectors. The governing equation for the solar collector is as follows [18]:

Here, , , and are collector constants and and are the mean collector temperature and ambient temperature, respectively. The area of the solar collector is calculated using the collector energy balance equation which is as follows: where , , and are the collector efficiency, area of the collector, and global radiation on the surface, respectively.

The net solar ORC efficiency of the system is given by the following equation: In another part of the research, the economic analysis for the hybrid system was conducted which included calculation of the net present value NPV, payback period, internal rate of return IRR, benefit-cost ratio BC ratio, and levelised cost of electricity production LCOE. The techno-economic analysis of the hybrid solar-geothermal ORC has the governing equations which are shown in Table 1.

The investigated site was on the location longitude: There are various hot springs in Nepal, but the Tatopani hot spring was one of the sites where the experimental work has been conducted. The site had not been contaminated, and the location for experiment was perfect. There was no any debris near the site source of hot spring. During the months of February and March, the Kaligandaki River has not affected the heat source site, but the effect can be seen when it was rainy season during July.

It was observed that the hot spring was used as recreational purposes in that location. The hot spring was pumped from the source in the pond for the storage and recreational activities such as bathing and refreshing. The nearby hot springs were quite far from the investigated location.

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The temperature of the source was almost constant through the measurement. Figure 3 shows the temperature profile of the hot spring on 31st October. The measured temperature was enough to observe the power output of the geothermal ORC system alone with two different organic working fluids Ra and Rfa by applying the obtained data on the developed model.

Furthermore, a series of experiment were carried out in order to find the maximum temperature of the hot spring when it was passed into the solar collector.

This final temperature was again applied in the model in order to observe the performance of the system by simulation results with the organic working fluids.

The model of the hybrid solar-geothermal ORC system consists of various main components such as pump, evaporator, expander, condenser, and solar field collector. The various thermodynamic parameters that were used for simulation of the overall performance of the hybrid system are shown in Table 2.

Based on these boundary conditions indicated in the table, the results for the system had been analyzed. There are various factors that affect the performance of the system, and the results are presented in this section.

The system efficiency is one of the most significant indexes for evaluating the characteristics and performance of the hybrid solar-geothermal ORC system technology. Two working fluids Ra and Rfa had been taken for investigation of the system performance. Ra suits well for a low-temperature heat source whereas Rfa can be used for a medium-temperature heat source.

The Carnot efficiency can be increased when the heat source temperature is increased and the temperature of the heat sink is lowered. Figure 4 shows the Carnot efficiency of the proposed hybrid solar-geothermal ORC system for the particular heat source temperature. The effect of thermal efficiency of the system changes with heat source temperature. The higher the heat source temperature, the higher the thermal efficiency. The rise in geothermal source temperature yields higher power output.
This trend is presented in Figure 5. The maximum thermal efficiency simulated was 8. Likewise, the net power output was found to be These performances on the thermal efficiency and net power output can be seen in Figure 6.

The hot spring temperature can be increased above the atmospheric pressure. If the system is assumed to have higher pressure for water, the performance of the system behaves differently. This is the optimal value for the system after simulation. The system pressure ratio determines the size, number, and type of expansion devices expander in the hybrid ORC technology.

The higher the pressure ratio, the higher the thermal efficiency of the system. Furthermore, a higher pressure ratio system requires an increased number of expanders.

In the case the system needs a higher number of expansion devices, it should be installed either in parallel or series for optimizing the performance of the system. In addition, the higher the pressure ratio, the higher the power output. Figure 8 shows that the shaft power mechanical power is Since the pressure ratio is small, the size of the expander is small and compact.

In the same figure Figure 8 , the pump power requirement is 1. Similarly, for the Rfa working fluid, the pressure ratio ranged from 3.

The pump power input was estimated around 1. This scenario was observed in the simulation results as presented in Figure 9. The solar collector area can be best calculated based on the solar isolation of that particular location. The solar collector area can be obtained according to the turbine inlet temperature. If the turbine inlet temperature is higher, the solar ORC efficiency is higher.

Figure 10 shows the effect of solar collector area requirement when the turbine inlet temperature changes. In addition, the net solar ORC efficiency can also be estimated with the collector area and the turbine inlet temperature. Similarly, the solar ORC efficiency could reach almost 9. The higher the collector efficiency, the higher the solar ORC system efficiency. The output of the solar ORC system depends mainly on the solar irradiance falling on the solar collector.

The maximum solar insolation yields a high value of power output from the ORC system. The maximum solar insolation falling on the experimental site is given by an author [19].

Figure 12 shows the monthly solar ORC power output for monthly average solar irradiance falling onto the solar collectors. The maximum power output can be estimated on the month of May. The least power output from the system was obtained during the month of December due to low solar insolation for that particular location.

The developed model of the hybrid solar-geothermal organic Rankine cycle system has been validated against the previous work of references indicated in Table 3. The results of the model are very closed and showed good agreement with the referenced work. This demonstrated that the developed model is viable for the system in this study. There are slight variations in the value obtained because several authors used different fluid property databases. The techno-economic analysis was carried out in order to estimate the levelised cost of electricity generation by this technology.

Furthermore, the economic indexes such as net present value NPV , payback period PB , internal rate of return IRR , and sensitivity analysis were estimated to find the details of economic importance for manufacturers, investors, stakeholders, and energy planners. The specific cost per kW of the hybrid solar-geothermal ORC system has been estimated by taking the reference [20].

The cost of working fluids Rfa and Ra was taken on the basis of references [20]. Table 4 shows the total capital cost for the hybrid solar-geothermal ORC system. The maximum percentage of the share in the system is for the solar ORC unit. Due to high cost of the solar collector, this part is quiet expensive as compared to solar PV. During the estimation of the economic index, the component cost and operation and maintenance cost have been taken into account.

It is assumed that the installation of the hybrid system is completed within one year. The salvage value for the system after 20 years is assumed to be zero.

Based on these assumptions, the economic indicators were presented. Rfa is quiet expensive as compared to other working fluids. Table 5 shows the capital cost, annual generation cost, and cost of electrical power generation for two different working fluids. Another economic indicator is the payback period of the installed system. The payback period is the number of years needed for the return of the investment. The return of investment can be achieved after 10 years of power generation. It is seen from the analysis that the hybrid solar-geothermal ORC system can be economically feasible when the LCOE is doubled with the cost of electricity production.

The same pattern is seen with the working fluid Rfa as presented in Figure The payback period for the system with the working fluid Rfa has quick return due to higher energy production of electricity with the same heat source temperature.

Likewise, the benefit-cost ratio and internal rate of return IRR are 1. The benefit-cost ratio is greater than 1 so it is a feasible investment. The calculation of techno-economic analysis for the hybrid solar-geothermal ORC system has been compared with the reference work as presented in Table 6.

It is illustrated that the cost of electricity production for the hybrid system was almost similar to the reference work. There are very less deviations in percentage from the calculated value.

This showed that the techno-economic evaluation calculation is acceptable. Sensitivity analysis is the method for evaluating the risk associated with the investment. The sensitivity analysis is carried out by taking the most influencing parameters that play an important role in making decision
The main objective of the research is to study the feasibility of electrical power generation by the concept of stand-alone hybrid solar-geothermal system. Therefore, the current research could address the potential for power generation by hot springs where the source temperature is enough to increase the temperature with a solar thermal collector, the temperature of the hot spring will be increased. This increase in temperature is enough to operate the ORC system.

There is not any literature which describes the potential of hot spring for power generation by the ORC technology. When the hot spring is coupled with a solar thermal collector, the temperature of the hot spring will be increased. This increase in temperature is enough to operate the ORC system. The authors reported that introduction of a solar parabolic trough field resulted in an increase in power production. Besides, an economic analysis was performed in order to obtain levelised cost of electricity for such hybrid system. Similarly, Shu et al. Another study investigated by Ghasemi et al. The results showed that the hybrid solar and geothermal plant yields 3.

The thermodynamic models were developed from the governing equations of ORC system components. The developed model predicted the performance of the system when the input parameters were given. The power output from the system was calculated to be more than 1. It was concluded that the working fluid R134a could get higher power output due to its thermo-physical characteristics when subjected to various temperature values.

In another part of the study, the techno-economic analysis was conducted for the hybrid system. The payback period, benefit-cost ratio, and IRR are 12 years. Therefore, the key finding is that the stand-alone hybrid solar-geothermal ORC system is feasible for power generation and is economically viable. The data used to support the findings of this study are available from the corresponding author upon request.

Suresh Baral. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. We will be providing unlimited waivers of publication charges for accepted articles related to COVID-19 up here as a reviewer to help fast-track new submissions.

Accepted 13 Aug 2020. Anthropogenic heat Surplus heat heat rejection. The fluid allows Rankine cycle heat recovery from lower temperature sources such as biomass combustion, industrial waste heat, geothermal heat, solar ponds etc. The low-temperature heat is converted into useful work, that can itself be converted into electricity.

The organic Rankine cycle, offered by companies such as Ormat, is a very known approach, whereby an organic substance is used as working medium instead of water.

Seasonal thermal energy storage Thermal energy storage Urban heat island Cooling tower Thermal power station. Harry Tabor H. Tabor and French immigrant Lucien Bronicki developed a small solar power unit, an Organic Rankine cycle turbine, for developing countries with problematic power grids. Waste heat recovery is one of the most important development fields for the organic Rankine cycle ORC.

Naphtha engines, similar in principle to ORC but developed for other applications, were in use as early as the s. Steamboat External combustion engine Naphtha Organic Rankine cycle. Fluoropolymer Fluorine Organo-fluorine chemistry Carbon—fluorine bond Refrigerant. Solution Dry cleaning Paint thinner Turpentine Acetone.

Plasma physics Metastability Spinodal decomposition Boiling point Liquid crystal. Liquid Boiling Vapor pressure Enthalpy of vaporization Phase transition. Rankine steam cycle Rankine engine.

The working principle of the organic Rankine cycle is the same as that of the Rankine cycle: the working fluid is pumped to a boiler where it is evaporated, passed through an expansion device turbine, screw, scroll, or other expander, and then through a condenser heat exchanger where it is finally re-condensed.

Boiler power generation Central heating Pulverized coal-fired boiler Boiler water Live steam.

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This information can be easily available in their websites. Moreover, the thermodynamic analysis in a steady state shall also be conducted for each thermal conversion unit and ORC unit. Various assumptions for modeling are as follows:

1. The calculation is based on steady-state conditions
2. The pressure drops in the heat exchangers are neglected
3. The heat losses from the various components are assumed to be negligible.

The general expressions for the energy balances of any steady state that are applied in each of the system components can be expressed as where subscripts in and out represent the inlet and outlet, respectively, and represent the mass flow rate and specific enthalpy, respectively, of the streams of the system working fluid, and represent the heat transfer and work transfer crossing the component boundaries, respectively. The ORC components in the system consist of a pump, an expander, an evaporator, and a condenser.

The main governing equations for the development of the models are described below: where and denote the pressure at the outlet and inlet of the pump, respectively. The abovementioned governing equations are based on basic laws of thermodynamics as presented by the authors [17].

The solar radiation data accounts for beam, diffuse, and reflected components of the solar irradiation. The model consists of computation of clear sky global irradiation on a horizontal surface and calculation of clear sky index, diffuse, and beam components on inclined surfaces.

The solar collector can be modeled for two different types of collector. They are non-concentrating and concentrating collectors. The governing equation for the solar collector is as follows [18]: Here, , and are collector constants and and are the mean collector temperature and ambient temperature, respectively.

The area of the solar collector is calculated using the collector energy balance equation which is as follows: where , and are the collector efficiency, area of the collector, and global radiation on the surface, respectively.

The net solar ORC efficiency of the system is given by the following equation. In another part of the research, the economic analysis for the hybrid system was conducted which included calculation of the net present value NPV, payback period, internal rate of return IRR, benefit-cost ratio BC ratio, and levelised cost of electricity production LCOE. The techno-economic analysis of the hybrid solar-geothermal ORC has the governing equations which are shown in Table 1.

The investigated site was on the location longitude: There are various hot springs in Nepal, but the Tatopani hot spring was one of the sites where the experimental work has been conducted. The site had not been contaminated, and the location for experiment was perfect.

There was no any debris near the site source of hot spring. During the months of February and March, the Kaligandaki River has not affected the heat source site, but the effect can be seen when it was rainy season during July. It was observed that the hot spring was used as recreational purposes in that location. The hot spring was pumped from the source in the pond for the storage and recreational activities such as bathing and refreshing.

The nearby hot springs were quite far from the investigated location. This was the preliminary investigation before conducting the experiment in order to study the feasibility of the power generation by the geothermal source hot spring ORC system. After the preliminary investigation of the source of the hot spring in the location, the temperature of the hot spring was measured. The data logger was used for measuring the temperature with thermocouples. The temperature of the source was almost constant through the measurement.

Figure 3 shows the temperature profile of the hot spring on 31st October. The measured temperature was enough to observe the power output of the geothermal ORC system alone with two different organic working fluids Ra and Rfa by applying the obtained data on the developed model. Furthermore, a series of experiment were carried out in order to find the maximum temperature of the hot spring when it was passed into the solar collector.

This final temperature was again applied in the model in order to observe the performance of the system by simulation results with the organic working fluids. The model of the hybrid solar-geothermal ORC system consists of various main components such as pump, evaporator, expander, condenser, and solar field collector. The various thermodynamic parameters that were used for simulation of the overall performance of the hybrid system were used for finding the maximum temperature of the hot spring when it was passed into the solar collector.
system are shown in Table 2. Based on these boundary conditions indicated in the table, the results for the system had been analyzed.

There are various factors that affect the performance of the system, and the results are presented in this section. The system efficiency is one of the most significant indexes for evaluating the characteristics and performance of the hybrid solar-geothermal ORC system technology.

Two working fluids Ra and Rfa had been taken for investigation of the system performance. Ra suits well for a low-temperature heat source whereas Rfa can be used for a medium-temperature heat source.

The Carnot efficiency can be increased when the heat source temperature is increased and the temperature of the heat sink is lowered. Figure 4 shows the Carnot efficiency of the proposed hybrid solar-geothermal ORC system for the particular heat source temperature. The effect of thermal efficiency of the system changes with heat source temperature.

The higher the heat source temperature, the higher the Carnot efficiency. The rise in geothermal source temperature yields higher power output. This trend is presented in Figure 5. The maximum thermal efficiency simulated was 8. Likewise, the net power output was found to be These performances on the thermal efficiency and net power output can be seen in Figure 6. The hot spring temperature can be increased above the atmospheric pressure.

If the system is assumed to have higher pressure for water, the performance of the system behaves differently.

This is the optimal value for the system after simulation. The system pressure ratio determines the size, number, and type of expansion devices expander in the hybrid ORC technology. The higher the pressure ratio, the higher the thermal efficiency of the system. Furthermore, a higher pressure ratio system requires an increased number of expanders. In the case the system needs a higher number of expansion devices, it should be installed either in parallel or series for optimizing the performance of the system.

In addition, the higher the pressure ratio, the higher the power output. Figure 8 shows that the shaft power mechanical power is Since the pressure ratio is small, the size of the expander is small and compact. In the same figure Figure 8, the pump power requirement is 1.

Similarly, for the Rfa working fluid, the pressure ratio ranged from 3. The pump power input was estimated around 1. This scenario was observed in the simulation results as presented in Figure 9. The solar collector area can be best calculated based on the solar isolation of that particular location. The solar collector area can be obtained according to the turbine inlet temperature. If the turbine inlet temperature is higher, the solar ORC efficiency is higher.

Figure 10 shows the effect of solar collector area requirement when the turbine inlet temperature changes. In addition, the net solar ORC efficiency can also be estimated with the collector area and the turbine inlet temperature.

Similarly, the solar ORC efficiency could reach almost 9. The higher the collector efficiency, the higher the solar ORC system efficiency. The output of the solar ORC system depends mainly on the solar irradiance falling on the solar collector. The maximum solar insolation yields a high value of power output from the ORC system.

The maximum solar insolation falling on the experimental site is given by an author [19]. Figure 12 shows the monthly solar ORC power output for monthly average solar irradiance falling onto the solar collectors.

The maximum power output can be estimated on the month of May. The least power output from the system was obtained during the month of December due to low solar insolation for that particular location. The developed model of the hybrid solar-geothermal organic Rankine cycle system has been validated against the previous work of references indicated in Table 3.

The results of the model are very closed and showed good agreement with the referenced work. This demonstrated that the developed model is viable for the system in this study. There are slight variations in the value obtained because several authors used different fluid property databases.

The techno-economic analysis was carried out in order to estimate the levelised cost of electricity generation by this technology. Furthermore, the economic indexes such as net present value NPV, payback period PB, internal rate of return IRR, and sensitivity analysis were estimated to find the details of economic importance for manufacturers, investors, stakeholders, and energy planners.

The specific cost per kW of the hybrid solar-geothermal ORC system has been estimated by taking the reference [20]. The cost of working fluids Rfa and Ra was taken on the basis of references [20]. Table 4 shows the total capital cost for the hybrid solar-geothermal ORC system.

The maximum percentage of the share in the system is for the solar ORC unit. Due to high cost of the solar collector, this part is quiet expensive as compared to solar PV. During the estimation of the economic index, the component cost and operation and maintenance cost have been taken into account. It is assumed that the installation of the hybrid system is completed within one year. The salvage value for the system after 20 years is assumed to be zero. Based on these assumptions, the economic indicators were presented.

Rfa is quiet expensive as compared to other working fluids. Table 5 shows the capital cost, annual generation cost, and cost of electrical power generation for two different working fluids. Another economic indicator is the payback period of the installed system.

The payback period is the number of years needed for the return of the investment. The return of investment can be achieved after 10 years of power generation.

It is seen from the analysis that the hybrid solar-geothermal ORC system can be economically feasible when the LCOE is doubled with the cost of electricity production. The same pattern is seen with the working fluid Rfa as presented in Figure 10. The payback period for the system with the
working fluid Rfa has quick return due to higher energy production of electricity with the same heat source temperature.

Likewise, the benefit-cost ratio and internal rate of return IRR are 1. The benefit-cost ratio is greater than 1 so it is a feasible investment. The calculation of techno-economic analysis for the hybrid solar-geothermal ORC system has been compared with the reference work as presented in Table 6. It is illustrated that the cost of electricity production for the hybrid system was almost similar to the reference work. There are very less deviations in percentage from the calculated value.

This showed that the techno-economic evaluation calculation is acceptable. Sensitivity analysis is the method for evaluating the risk associated with the investment. The sensitivity analysis is carried out by taking the most influencing parameters that play an important role in making decision whether it is worth investing or not.

In the present study, annual power production, annual equivalent cost, and interest rate have been chosen for the analysis.

The analysis was carried out for both of the working fluids Ra and Rfa. The possibility of increment in annual production is running the ORC system for all hours throughout the year. A similar pattern is seen for the working fluid Rfa, when there is an annual power production increment from the hybrid. The results of the sensitivity analysis can be observed from Table 8. Here, the payback period is only 5. In Figures 15 and 16, the variation of the net present value NPV for all three different scenarios was examined and illustrated the importance of influencing parameters for the hybrid solar-geothermal ORC system.

The highest dependency of NPV is for annual production of power followed by annual equivalent cost for both of the working fluids. The NPV should be positive in order to be feasibly invested. Figure 15 shows a slightly curvature type of profile; this is due to the negative NPV for the system. The study reported the feasibility analysis of the stand-alone hybrid solar-geothermal organic Rankine cycle technology for power generation in Bhurung Tatopani, Myagdi. The experiment conducted on the Tatopani site revealed the temperature of the hot spring to be Another experiment included feeding of the hot spring into the solar collector in order to observe the temperature increment which can be applied in the developed model.

The thermodynamic models were developed from the governing equations of ORC system components. The developed model predicted the performance of the system when the input parameters were given. The power output from the system was It was concluded that the working fluid Rfa could get higher power output due to its thermo-physical characteristics when subjected to various temperature values.

In another part of the study, the techno-economic analysis was conducted for the hybrid system. The payback period, benefit-cost ratio, and IRR are 12 years, 1. Therefore, the key finding is that the stand-alone hybrid solar-geothermal ORC system is feasible for power generation and is economically viable. The data used to support the findings of this study are available from the corresponding author upon request.

Two heat exchangers have been designed for the ORC prototype, one is an air cooled cross-flow heat exchanger for cooling the hot organic vapours and one shell and tube condenser water cooled for condensing the vapour into liquid state.

Theoretical modelling of the prototype assembly is done using DWSIM and thermo-economic analysis has been carried out. Results indicate that the system can generate electricity in the range W. The 1st law and 2nd law efficiencies of the cycle varies from The payback period for the system is estimated to be around Leiria, September Lemort, L.
