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RESEARCH PAPER

Developing an Environmental-Friendly Trend of Thermal and Electrical Load Profiles in Ilam Industrial Town

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ABSTRACT
Recently, making use of emerging fuels such as municipal waste has been proposed as an alternative for conventional fuels and also as a way for municipal waste disposal. This research, while modeling the thermal and electrical profiles of Ilam Industrial Town, examines the possibility of supplying the required fuel from municipal waste by the year 2041. For this purpose, different combined heat and power (CHP) scenarios were implemented in the LEAP software. According to the results, electricity generation will start gradually from the year of operation of the power plants in 2025 and reach more than 4.3 GWh in 2026. The production process will be incremental and is expected to reach 115.9, 119.1, 111.8, 118.4, 123.1, 118.9, 118.4, 118.4 GWh, respectively under the scenarios of gasifier CHP, CHP turbine incinerator, CHP steam incinerator, landfill CHP, syngas CHP, anaerobic digester CHP, combined gasifier and incinerator CHP, and ultimately improve to 118.9 GWh under the scenario of optimized gasifier and incinerator CHP. The required power plant capacity under the above-mentioned scenarios is expected to be approximately 21 MW by the year 2041and modify to 20.5 MW under the optimization scenario. The incinerator, combined-incinerator-and-gasifier, and optimization scenarios meet the supply and demand conditions of the generated waste, and in other scenarios, either the CHP supply share should be lower than 50% or the additional waste should be supplied from the nearby villages and towns.

KEYWORDS: energy, supply, demand, waste

INTRODUCTION

Demand for industrial products combined with energy consumption and CO2 emissions have increased significantly in the last two decades (Nejat et al., 2015; Saidi & Hammami, 2015; Rahmani et al., 2020). The industrial sector accounted for 37% (157 EJ) of the world's total final energy consumption in 2018, representing a 0.9% annual increase in energy consumption since 2010, plus 0.8% growth in 2018 and a sharp growth of 1.6% compared to the previous year. This growth in energy consumption is further influenced by the long-term trend of increasing production in energy-intensive industrial subdivisions (e.g. chemicals, iron and steel, cement, pulp, and aluminum) (IEA, 2020). Industrial areas, where several industrial

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units are located and operate simultaneously, face the challenge of continuous and sustainable energy supply (Masera & Faaij, 2014; Yadav et al., 2020). Planning and responding to this growing need is not possible without accurate calculations and taking into account all the influencing factors, and modeling can be a supportive tool for this purpose (Cavallaro, 2013; Ringkjøb et al., 2018). Energy modeling tools, by creating interconnected mechanisms, provide an integrated understanding of energy systems (al Irsyad et al., 2017). Understanding and realistic analysis of energy systems allows researchers, planners, and decision-makers to monitor more accurately the current state of the systems and with a correct understanding of the perspective of energy systems in the form of possible scenarios, make the best decision to improve, guide, and stabilize processes. This is especially important for industrial areas where durability and sustainability are highly dependent on sustainable fuel and energy supply. Estimating the future power needs and planning how to meet the demands is one of the important aspects of management of industrial areas, which is often not easily possible due to the complexity of the energy supply and demand system. The method that has attracted a lot of attention today is the combined heat and power (CHP) as a highly fuel-efficient system (Motevasel et al., 2013; Mehdinejad et al., 2017; Yang et al., 2017; Aliehyaei, 2020). The average efficiency of a power generator is about 35%, while a CHP system, with the production of both heat and power products, has an efficiency of more than 85% (Krishna et al., 2010; Odeh et al., 2015; Mărcuş et al., 2019); about 35% in terms of electrical efficiency and 50% in terms of thermal efficiency. These systems consume about 35% less fuel compared to the similar conventional separate heat and power generation systems (Shepard, 2016; Riley et al., 2020). Aside from benefits such as greater energy efficiency, the use of waste to generate fuel for power plants has recently come into sharp focus (Pan et al., 2020). In addition to higher fuel supply efficiency, CHP incinerators can help dispose of waste in cities (Wu et al., 2018; Amaral et al., 2020). Waste-to-Energy (WtE) CHP units are recognized as the best way to recover energy from waste (Lombardi & Carnevale, 2018). However, one issue that challenges the use of these systems operationally and technically is the *efficiency* of energy recovery from waste (Uche-Soria & Rodríguez-Monroy, 2019; Levaggi et al., 2020).

High levels of energy recovery efficiency are critical for the environmental sustainability of WtE power plants so that the more electricity and heat generated, the more natural resources can be preserved (Lombardi & Carnevale 2018). Accordingly, before establishing such units, it is necessary to carefully consider the feasibility of their use from a technical, operational, and economic point of view. This study is an attempt to estimate the future trend of demand and supply in an industrial town in Iran in the period 2017-2041 and examine the ways to meet the demand under the different scenarios. Feasibility study of supplying all or part of the energy demand in this industrial area is another important goal of this research. .

MATERIAL AND METHODS

The LEAP model was used to estimate the electrical thermal profile of Ilam Industrial Town. The studied energy system was the industrial town (as an energy applicant) and the waste disposal site and in addition to conventional energy carriers such as natural gas, oil products and electricity, municipal waste was also considered as an energy source. For the combined generation of electricity and heat, the following technologies with different characteristics (scenarios) were considered, which are fed from different energy sources to generate heat and electricity:

- Combined heat and power generation by gas turbines

- Combined heat and power generation from natural gas with the internal combustion engine technology
- Combined heat and power generation from waste with waste incineration technology by directing the combustion gas in the incinerator (waste incinerator) to the gas turbine
- Combined heat and power generation from waste with waste incineration technology by producing steam in the boiler and transferring it to the power plant
- Combined heat and power generation from waste with gasification technology (Gasifier, highly suitable for large-volume waste sources): In this technology, the syngas is first generated from waste by chemical methods in the gasification machine and then transferred to the CHP power plant and gas turbine.
- Combined heat and power generation from waste with landfill technology: In this technology, the waste is first buried in the ground with a specific technique and then collected through different landfill gas systems. The gas is pressurized and transferred to a CHP turbine power plant to generate electricity and heat.
- Combined heat and power generation from waste with anaerobic digestion technology: In this technology, first dry and wet anaerobic systems produce gas from waste and then the gas is collected and treated through various systems. After pressurizing the gas, it is transferred to the CHP turbine power plant to generate electricity and heat.

as mentioned earlier, the LEAP model was used to estimate the energy demand of the industrial zone in the period of 2017 (as the base year) and 2041 (as the model horizon) under the different scenarios. The demand-side formula of the model was as follow:

$$E_{i,h,t} = \sum_{k=1}^{K}\sum_{m=1}^{M} A_{i,j,k,m,t} \times EI_{i,j.k,m,t} \qquad (1)$$

where;

i= Ilam Industrial Town, j= energy carrier, k=main sub-unit, m=end use of heat and power energy (e.g. gasoil), t= year, Ei,j,t= Demand for energy carrier i is in the section j, and EIi,j,t= Intensity of energy consumption (in gigajoules per ton or joules per dollar of value added).

Also, the main mathematical supply-side equation of energy balance was:

$$P + \mathrm{Im} >= FD + Loss + Ex + NeD \qquad (2)$$

$$EnIn = \frac{EnEx}{\eta} \qquad (3)$$

In which;

P= generation level of each system, Im= input from outside the boundary of the energy system, FD= downstream energy requirements (final demand), Loss= system losses, Ex= exports from the system to outside, NeD= a non-energy consumption (e.g. petrochemical feed, which in this study, there is no such consumption), EnIn= the energy inputted to each system, EnEx= the output from each system, and n= efficiency of the system. The EnIn balance must be established in each system (Nieves et al., 2019).

The average calorific value of waste was obtained from the following equation and according to the different compositions of the municipal waste:

$$CV = \sum_{i=1}^{N} W_i \times C_i \qquad (4)$$

Where;

CV= average calorific value of the waste, i= number of identical main items in the waste (such as food and organic materials, plastic, wood rubber, paper, etc.), Wi= weight percentage of material I, and Ci= caloric value of material i (mega joules per kg). The energy that can be produced from waste is calculated as below:

$$P_{kw} = (T_{t/d}) \times (1_{d/24h}) \times (CV_{Mj/Kg}) \times (1/3.6) * (\eta) \quad (5)$$

where;

P= electricity power extracted by incinerating, T= waste generation per day, and CV= calorific value, and n= system efficiency.

At present, the total waste generated in Ilam is about 90 thousand tons per year, of which about 81 thousand tons per year can be used for energy generation. The average calorific value of the mixed waste is 7.3; 15 for dry waste and 5.9 for wet waste.

RESULTS AND DISCUSSION

Energy supply and demand analysis in Ilam Industrial Town: The distribution of demand for energy carriers in the main industrial subdivisions of Ilam Industrial Town shows that the chemical industries with a share of 53.8% have the highest share, followed by food and textile industries. According to the load changes in different months of the year, the highest energy load needs are met in winter, which is due to the increased need for space heating in industrial units. Changes in the monthly electricity demand load of industrial units, in contrast to the demand for natural gas and total energy, occur in summer, due to the need to cool the space and increase electricity demand in industrial units. With the replacement of heat instead of natural gas, and CHP electricity instead of grid electricity in potential industries, the demand for grid electricity and natural gas is expected to change in other scenarios (Figs. 1 and 2). Assuming 50% energy demand coverage of industrial units by CHP units, the demand for natural gas will increase from about 46 million cubic meters to 64 million cubic meters in the research horizon, which shows a decrease of more than 30 million cubic meters per year compared to the baseline scenario. The deficit can be supplied from waste or other sources.

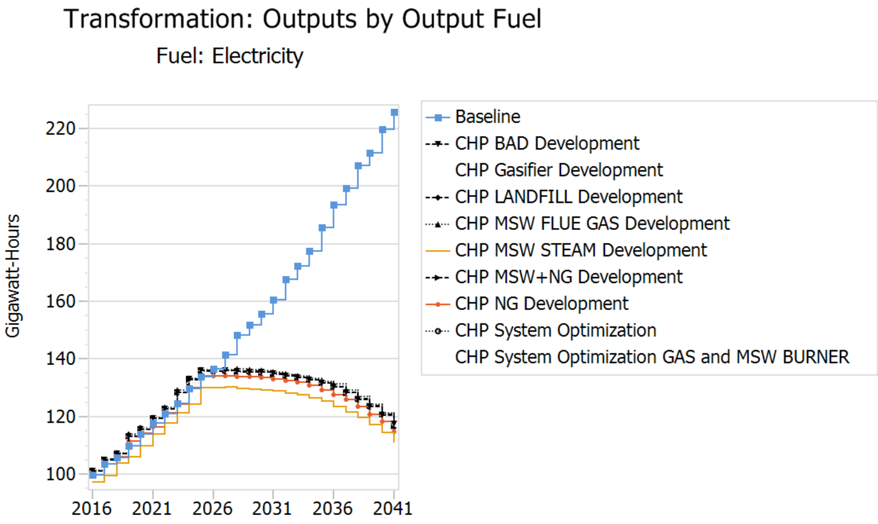

Fig. 1. Process of generating electricity in national power plants to supply the required electricity of Ilam Industrial Town

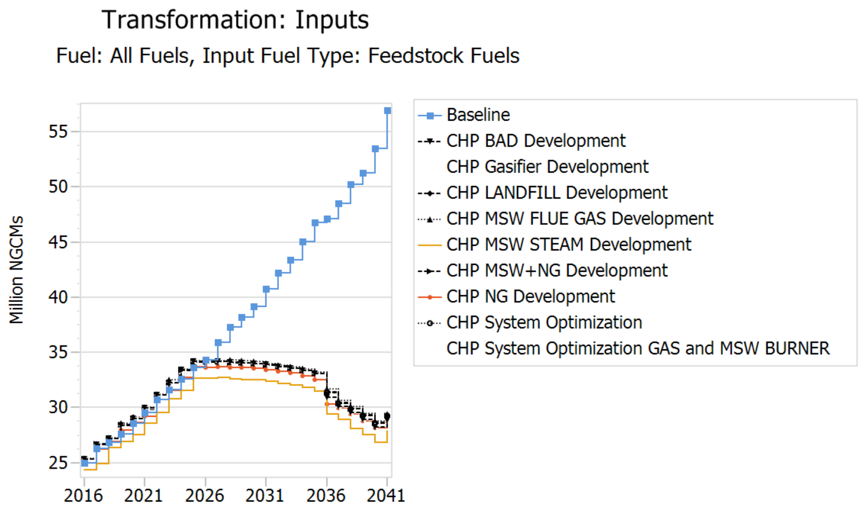

Fig. 2. Trend of natural gas consumption by national power plants to supply electricity demand of the industrial estate through the national grid

Another important output indicator is the amount of fuel consumption in national power plants to supply the electricity demand the industrial town. The results show that the total demand will vary in the range 24-57 million cubic meters per year over the study period under the reference scenario.

Analysis of CHP system output indicators: The model outputs show that the amount of electricity generation in CHP power plants varies in different scenarios and technologies (Fig. 3). In 2025, with the construction of power plants, electricity production will gradually begin and will reach more than 4.3 GWh by 2026. The uptrend of power generation is expected to reach 115.9, 119.1, 111.8, 118.4, 123.1, 118.9, 118.4, and 118.4 GWh under the scenarios of gas CHP, turbine incinerator CHP, steam incinerator CHP, landfill CHP, syngas CHP, anaerobic digester CHP, combined-gas-and-incinerator CHP, optimized combined-gas-and-incinerator CHP, respectively, and finally reach to 118.9 GWh in the scenario of optimizing the integration of gas and incinerator scenarios. The designed CHP capacity index for each of the scenarios and technologies is also expected to change as shown in Fig. 4.

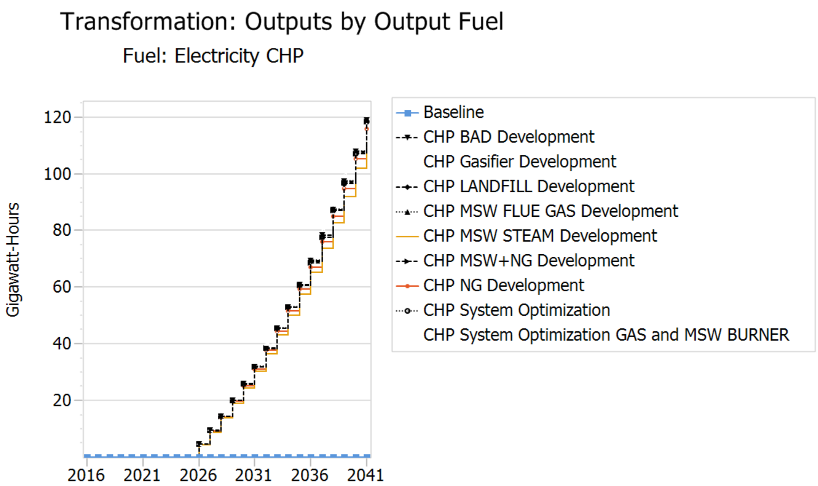

Fig. 3. Power generation trend in CHP power plants under different scenarios

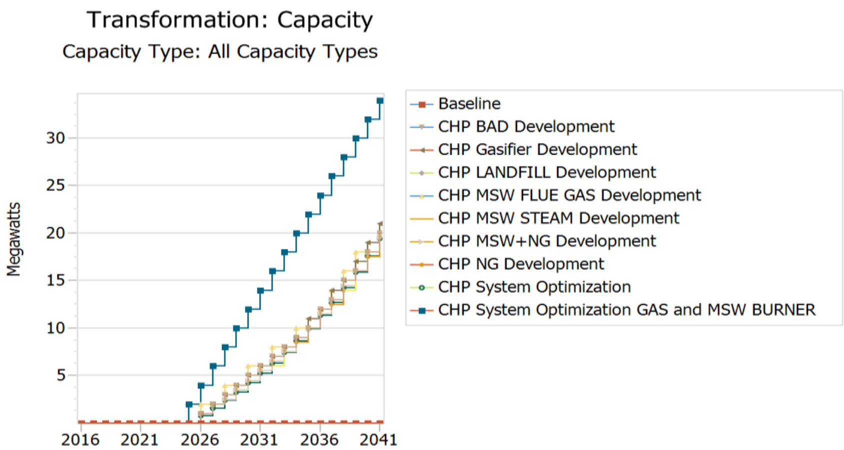

Fig. 4. Capacity-building trend in the CHP power plants under different scenarios

Table 1 shows the designed capacity of the different types of power plants required to supply 50% of the town's energy in 2041. As observed, the required power plant capacity is expected to be 20.5, 22, 22, 20, 21, 21, 21, 20.5, 20.1 MW, respectively under the gas CHP, turbine incinerator CHP, steam incinerator CHP, landfill CHP, syngas CHP, anaerobic digester CHP, gas and waste incinerator CHP, optimized scenarios by the year 2041 and finally to 20.5 MW in the scenario of optimizing the combination of waste and gas power plants. The surplus generated electricity will probably be exported to the national grid. Fig. 5 depicts the demand for municipal waste that can be used to generate energy in different scenarios. According to the figure, the highest demand will occur in the scenarios of landfill CHP, anaerobic digester, and gasifier, respectively, and the lowest in the turbine incinerator system. The current volume of waste will not be able to meet entirely the existing demand of industries. Three scenarios, including incinerator CHP, combined-waste-incinerator-and-gas CHP, and optimization, meet the supply and demand conditions of waste to energy conversion. In other scenarios, either the energy supply share of CHP must fall below 50% or an additional waste must be supplied from the surrounding villages and towns.

Table 1. Supply and demand of waste for energy supply in Ilam Industrial Town

Scenarios (GWh)	**Year**													
	2016	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2030**	**2035**	**2040**	**2041**
Baseline	81.1	83.0	85.0	87.0	89.0	91.0	93.1	95.2	97.3	99.5	110.6	122.3	134.6	137.1
CHP BAD Development	81.1	83.0	85.0	87.0	89.0	91.0	93.1	95.2	97.3	99.5	79.7	-2.9	-110.9	-137.5
CHP Gasifier Development	81.1	83.0	85.0	87.0	89.0	91.0	93.1	95.2	97.3	99.5	75.6	9.2	-80.1	-101.9
CHP Landfill Development	81.1	83.0	85.0	87.0	89.0	91.0	93.1	95.2	97.3	99.5	66.2	-14.2	-129.1	-155.7
CHP MSW Flue Gas Development	81.1	83.0	85.0	87.0	89.0	91.0	93.1	95.2	97.3	99.5	88.7	53.3	2.8	-10.0
CHP MSW Steam Development	81.1	83.0	85.0	87.0	89.0	91.0	93.1	95.2	97.3	99.5	93.6	69.0	32.9	23.6
CHP MSW+NG Development	81.1	83.0	85.0	87.0	89.0	91.0	93.1	95.2	97.3	99.5	100.6	87.7	64.5	62.5
CHP NG Development	81.1	83.0	85.0	87.0	89.0	91.0	93.1	95.2	97.3	99.5	110.6	122.3	134.6	137.1
CHP System Optimization	81.1	83.0	85.0	87.0	89.0	91.0	93.1	95.2	97.3	99.5	90.4	59.1	13.2	2.3
CHP System Optimization Gas and MSW Incinerator	81.1	83.0	85.0	87.0	89.0	91.0	93.1	95.2	97.3	99.5	88.7	53.1	2.6	-10.0

Note: The negative sign indicates demand and the positive indicates supply

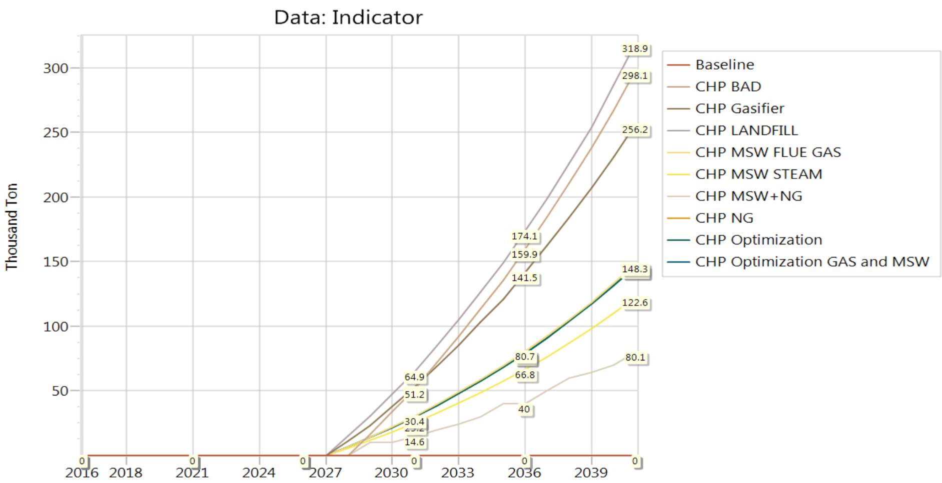

Fig. 5. Demand for the usable municipal waste to generate energy under the different scenarios

Environmental emissions

The trend of greenhouse gas emissions under the different scenarios are presented in Table 2. As the table suggests, the total amount of greenhouse gas emissions will increase from about 317 thousand tons equivalent to carbon dioxide in the base year to about 192 thousand tons in 2041 under the optimized gasifier and incinerator scenario, i.e. a reduction of 125 thousand tons during the study period.

Table 2. Emission trends in each of the possible scenarios (Million tons of equivalent carbon dioxide)

Scenarios	2016	2017	2018	2019	2020	2025	2030	2035	2040	2041
Baseline	317.3	325.4	336.4	344.1	354.8	404.4	461.1	526.2	597.7	616.8
CHP BAD	317.3	333.6	342.1	353.0	361.3	413.9	388.5	243.5	263.9	272.4
CHP Gasifier	317.3	334.3	342.6	352.2	362.1	413.6	381.4	254.5	267.4	276.2
CHP LANDFILL	317.3	334.6	342.6	352.9	361.6	413.9	358.9	243.7	264.6	272.7
CHP MSW FLUE GAS	317.3	324.1	332.4	342.2	350.9	402.8	387.6	321.0	214.2	192.2
CHP MSW STEAM	317.3	325.9	336.4	344.1	354.3	404.2	396.7	345.7	258.0	240.8
CHP MSW+NG	317.3	325.7	336.2	344.0	353.7	405.0	417.3	398.8	350.9	349.6
CHP NG	317.3	325.7	336.1	344.0	354.1	405.2	447.6	494.4	538.8	552.1
CHP Optimization	317.3	326.0	335.5	344.5	354.7	405.2	389.8	325.5	216.1	195.0
CHP Optimization GAS and MSW	317.3	324.0	332.3	342.7	351.0	402.8	386.7	321.2	213.9	192.2

Economic feasibility The economic feasibility of the scenarios compared to the reference scenario was analyzed based USD value in 2015. As shown in Table 3, optimized gasifier and incinerator CHP would be the preferred scenario.

Table 3. Cost-benefit analysis of different energy supply scenarios in Ilam Industrial Town

Cumulative Costs & Benefits: 2016-2041. Relative to Scenario: Baseline. Discounted at 5.0% to year 2016. Units: Million 2015 U.S. Dollar	CHP NG	CHP MSW STEAM	CHP LANDFILL	CHP BAD	CHP Gasifier	CHP MSW+NG	CHP Optimization	CHP MSW FLUE GAS	CHP Optimization GAS and MSW
Demand	-	-	-	-	-	-	-	-	-
Ilam Industrial Park	-	-	-	-	-	-	-	-	-
Transformation	-3.949	7.857	13.288	17.467	27.219	0.266	2.949	7.144	6.710
Electricity Network	-6.958	-6.960	-6.961	-6.964	-6.961	-6.961	-6.963	-6.933	-6.951
Electricity Generation	-2.123	-2.002	-2.123	-1.670	-1.670	-2.123	-2.141	-2.000	-2.140
CHP Elec Transport	3.082	3.096	3.082	3.419	4.047	3.082	3.082	3.132	3.087
Heat Transport	1.975	1.981	1.974	2.149	2.549	1.974	1.972	2.000	1.977
CHP Generation System	1.863	15.389	20.969	24.195	32.861	7.241	10.629	14.565	14.378
Natural Gas Transport	-1.788	-3.648	-3.652	-3.662	-3.608	-2.948	-3.631	-3.620	-3.642
Resources	-25.972	-53.915	-46.047	-45.082	-46.695	-42.818	-53.269	-52.826	-54.015
Production	-	-	-	-	-	-	-	-	-
Imports	-25.972	-53.915	-46.047	-45.082	-46.695	-42.818	-53.269	-52.826	-54.015
Exports	-	-	-	-	-	-	-0.000	-	-0.000
Unmet Requirements	-	-	-	-	-	-	-	-	-
Environmental Externalities	-2.041	-2.992	-1.912	-1.940	-1.777	-2.554	-2.730	-2.660	-2.705
Non Energy Sector Costs	4.207	3.081	2.181	2.315	2.320	3.483	2.867	2.845	2.846
Net Present Value	-27.754	-45.969	-32.491	-27.240	-18.933	-41.624	-50.184	-45.498	-47.165
GHG Savings (Mill Tonnes CO2e)	0.472	2.598	3.369	3.181	3.136	1.817	2.900	2.931	2.934
Cost of Avoiding GHGs (U.S. Dollar/Tonne CO2e)	-58.817	-17.692	-9.644	-8.564	-6.038	-22.906	-17.307	-15.525	-16.076

Sensitivity analysis To analyze the sensitivity of the model, the share of electricity supply of industries from CHP was changed in 10%-intervals (Table 4) to check how the main design parameters of the CHP system would change with the fluctuations in the share of CHP energy supply system. The waste generated in the city by 2041 can supply about half of the energy demand of the industrial unit.

Table 4. Effect of changes in the share of electricity supply in the industrial town from CHP on the model outputs under the superior scenario

No.	CHP contribution to industrial energy supply	Net present value (million dollar)	Cost of carbon reduction (USD/t CO2 eq)	Waste balance (ton per year)	Required capacity of CHP power plant	
					Gasifier	Incinerator
					MW	MW
	20	-16.4	-14.1	81.7	1.2	6.4
	30	-29.6	-16.6	53.2	1.8	9.8
	40	-34.5	-16.3	31.0	2.2	12.4
	49.9	-46.6	-16.6	0	2.8	15.5
	50	-54.1	-17.7	0	4.2	15.5
	60	-61.0	-16.7	0	8.3	15.5
	70	-72.0	-16.9	0	12.2	15.5
	80	-78.8	-16.4	0	15.7	15.5
	90	-82.8	-16.3	0	17.4	15.5
	100	-92.0	-16.2	0	21.4	15.5

According to the findings, with the replacement of heat instead of natural gas, and CHP electricity instead of grid electricity in potential industries of the industrial town, the demand for electricity and natural gas in the national grid is expected to change. Assuming that 50% of the energy demand of the industrial units is covered, the demand for natural gas in the industrial area is expected to decrease by more than 30 million cubic meters per year, which can be met from waste or other sources. In a similar conclusion, Chaliki et al., (2016), while reviewing WtE power plants in European countries, assessed the use of these power plants environmentally, technically, and economically feasible and introduced them as a factor of sustainability of sustainable European cities (Chaliki et al., 2016). Guo et al., (2015) in a study on the feasibility of establishing a WtE power plant in Baotou, China, while confirming the technical and economic feasibility of the power plant, claimed that the plant will inject up to 20 MW of electricity into the grid (Guo, 2015). Kalyani and Pandey in 2014 considered the establishment of WtE conversion systems appropriate for India, with a population of 1.2 billion and a per capita production of 0.5 kg of waste per day (Kalyani & Pandey, 2014). Using a similar approach, Korai et al., (2017) calculated that by adopting the process of converting waste into energy, the energy load on Pakistan's primary resources would be reduced by 1.86% (Korai et al., 2017). Abdallah et al., (2018), while proving the justifiability of WtE conversion systems in the UAE, concluded that the use of waste incineration and anaerobic digestion strategies could convert at least 52.4 and 31.2 million tons of processed waste into energy, respectively (Abdallah et al., 2018). Tan et al., (2015) evaluated the justifiability of WtE conversion systems in Malaysia and reported that incinerators would be preferred when both heat and electricity generation is considered, and anaerobic digestion systems when only electricity generation is intended (Tan et al., 2015). In conclusion similar to the findings of this study, almost all studies have considered the use of WtE conversion systems to be technically feasible and environmentally justifiable.

CONCLUSION

The present study was conducted with the aim of predicting the future supply and demand of Ilam Industrial Town under different scenarios of combined generation of electricity and heat from waste in Ilam City in the years between 2016 to 2041. The research findings predicted a growth of 3.35% and. 3.29% in the demand for energy carriers. Based on the model outputs, the optimized gasifier and incinerator scenario would be a superior option technically, economically, and environmentally. During this period, the natural gas potential was predicted to increase over 55 million cubic meters and the demand for electricity to more than 120 GWh. The maximum power capacity required to meet this demand in the model horizon was estimated at 22 MW under the baseline scenario and about 20 MW in other scenarios. Electricity generation will gradually start from the year of construction of power plants in 2025 and will reach more than 4.3 GWh in 2026. Also, the heat demand of the CHP power plants under the different scenarios was expected to range between 37.5 to 40.1 million cubic meters equivalent to natural gas. Overall, this study technically confirms the feasibility of using WtE conversion systems in Ilam Industrial Town. However, detailed justification of the project is proposed to be comprehensively examined in the form of various economic and environmental scenarios, as future works.

GRANT SUPPORT DETAILS

The present research did not receive any financial support.

CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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