Energy Efficiency Improvement by Integrating Cryptocurrency Miners in An Energy Hub Framework

M. Makki [1], M. Rashidinejad[1]*, A. Abdollahi[1], M.R. Salehizadeh[2]

[1] Department of Electrical Engineering, Shahid Bahonar University of Kerman, Kerman, Iran
(e-mail: miladmaki74@gmail.com), (e-mail: mrashidi@uk.ac.ir), (e-mail: a.abdollahi@uk.ac.ir).

[2] Department of Electrical Engineering, Marvdasht Branch, Islamic Azad University, Marvdasht, Iran
(e-mail: salehizadeh@miau.ac.ir).

*Corresponding Author

Received 07 May 2022 Received in revised form 22 Oct. 2022 Accepted 20 Nov. 2022

Type of Article: Research paper

***Abstract*- Following population growth, the need for food is increased all over the world. In this regard, investment in greenhouses becomes an attractive solution to produce fresh agricultural products. In some parts of Iran, greenhouses are usually located next to residential buildings in rural areas. Both residential buildings and greenhouses consume electrical and thermal energy. In this regard, they can be considered in an energy hub in which photovoltaic (PV) systems and combined heat and power units (CHP) are used as the sources of electrical and thermal energies. This energy hub can be connected to the distribution network for the energy exchange. To enhance economic profit, cryptocurrency miners can be integrated into the energy hub. From the energy perspective, cryptocurrency miners consume electrical energy and produce heat. In this regard, the configuration of the energy hub becomes more complex and requires an optimal operational management and energy efficiency improvement mechanism. To this purpose, this paper presents a novel optimization framework by considering electrical energy storing, CO2 capturing, and miner heat recycling. This energy hub has been investigated for a rural residential hub in Golzar area, Kerman province of Iran, and the results are analyzed.**

***Keywords*: Cryptocurrency Miner, Energy Hub, Energy Efficiency, Greenhouse, Rural area**

Nomenclature

Indices

t	Index of time
d	Index of day

Parameters

$P_{CH_{max}}$, $P_{dCH_{max}}$	Maximum charging and discharging capacity of storage
W	A large number
$H_d(t)$	Thermal demand of residential building studied
$H_{CHP_{max}}$	Maximum heat generated by CHP
$C_e(t), C_g(t)$	Electricity and gas tariffs based on usage time
A	Conversion coefficient of gas usage to electricity usage
$P_{CHP_{max}}, P_{CHP_{min}}$	Maximum/minimum power generated by CHP
$P_{PV}(t)$	Power generated by photovoltaic
$E_{batt_{max}}$	Maximum energy capacity of storage
α_1, α_2, α_3	The coefficient of use of electricity in any period
β_1, β_2, β_3	The coefficient of use of electricity in any period
η_{eCHP}	CHP unit efficiency
η_{dc}	The efficiency of DC connector to AC

Variables

$E_{in}(t)$	Electrical power is imported from the grid to the

[DOI: 10.61186/joc.17.3.67]

	energy hub of the residential building
$H_{CHP}(t)$	Thermal power generated by the CHP unit
$P_{CH_{batt}}(t)$, $P_{dCH_{batt}}(t)$	Energy consumed and produced by electrical storage
$P_{H2G}(t)$	Electrical power injected from the energy hub into the grid per hour
$P_{CHP}(t)$	Power generated by CHP
$Q_T(t)$	Total energy imported into the building per day
R	Energy label index
$SOC(t)$	Energy levels of storage
$I_{CH}(t), I_{dCH}(t)$	Binary variable indicating the charge/discharge status of the storage
$I_{CHP}(t)$	Binary variable indicating the status of CHP
SEC_e	Specific thermal energy consumption
SEC_{th}	Specific electrical energy consumption
SEC_{tot}	Total specific energy consumption
EE	Electrical energy consumption of greenhouse
C_{CHP}	Carbon dioxide produced by CHP
F_{CHP}	Fuel consumption by CHP

Acronyms

$GAMS$	General Algebraic Modeling System
CHP	Combined Heat and Power
EUI_{actual}	Actual Energy Usage Intensity
EUI_{ideal}	Ideal Energy Usage Intensity
TOU	Time Of Use

I. INTRODUCTION

A. Problem statement

As time passes and the human population increases, the need for food also increases. Nowadays, about 45% of the world's food is supplied by agricultural ecosystems [1]. To meet the world's demand in 2050, it must reach 70% [2]. For instance, promoting agriculture in a controlled area such as greenhouses is an effective way to increase the production of crops. In this regard, in recent decades, greenhouse cultivation has expanded in many parts of the world [3]. In some rural areas, small greenhouses are located near residential buildings. It is noted that these agricultural greenhouses consume more energy in mechanical systems than other similar-sized buildings [۴]. Accordingly, designing a new framework for integrating greenhouse and residential buildings in an energy hub is necessary. In addition, to improve economic profit, the energy hub can be integrated by cryptocurrency miners. Cryptocurrency miners consume electrical energy and produce heat. In this regard, the configuration of the energy hub becomes more complex and requires an accurate energy management and energy efficiency improvement mechanism. It is mentioned that some research has been done on reducing energy consumption and greenhouse gas emissions of greenhouses in the industrial level. For example, in [5], a CHP is used to supply the thermal and electrical demand of the greenhouse on the megawatt-scale. In [6], a CCHP is used on a megawatt scale to meet greenhouse demand. Despite these research activities in industrial level, studying energy efficiency of greenhouses in residential level is a need that has been addressed in this paper. In the following sub-sections, we review some new advancements in energy hubs, cryptocurrency miner, and energy efficiency.

B. Energy hub

Some studies have been working on energy management and evaluating the impact of different elements on energy consumption. In [۷], the effect of storage (both electrical and thermal) on the residential energy hub has been investigated .In [۸], electrical and thermal storage, demand response, photovoltaic, CCHPs, and electric vehicles are considered in the energy hub. In [۹], to improve energy efficiency CHP, photovoltaics, renewable energy, electric vehicles, and demand response are considered in the energy hub .In [۱۰], for a building energy management system, fuel cells, storage, and demand response program are considered .In [11], a comprehensive structure for the optimal performance of the energy hubs with wind power penetration is provided. A structure for an energy hub is proposed in [12]. This structure is provided for coastal urban areas to increase energy efficiency and reduce energy costs. CHP, PV, and a wind turbine are used in this structure .In [13] smart water and energy hubs have been considered, and their uncertainty management has been investigated.

In the context of hybrid renewable energy sources (HRES), other studies have been done, among which we can mention: [14], which uses wind and solar power in the energy hub for optimal sizing by techno-enviro-economic assessment. In [15], solar energy and fuel cell are used in an energy hub, and optimal heat recovery by techno enviro-economic assessment is made in this article. In [16], solar energy, wind energy, and fuel cell are used in an energy hub, and risk-based optimal operation considering demand response programs (DRPs) and electric vehicles (EVs) has been investigated in this paper.

In [17], stochastic operation considering load uncertainty has been studied in this paper, and solar energy and fuel cell have been used in the energy hub.

[DOI: 10.61186/joc.17.3.67]

Optimum design for residential load considering EVs has been done in [18], and solar energy, wind energy, fuel cell energy, and biogas have been used in the energy hub. In [19], a techno-enviro-economic assessment has been done, and wind energy, solar energy, and biogas have been used in the energy hub. In [20], optimal design for residential SEH based on building clusters has been done, and solar energy and biogas have been used in the energy hub.

C. Cryptocurrency miner

One of the main challenges facing cryptocurrency miners is the remarkable consumption of its miners. Using the advantages of distributed generation resources (DGRS) is one way to tackle this challenge [٢١].In recent years, some research has also been conducted on feeding cryptocurrency miners with renewable energy. For example, in [22], fuel cells and biogas energy were used to feed cryptocurrency miners, and to analyze the investment in a BTC mining farm an economic model is presented. A method for supplying electricity to cryptocurrency mining devices and cooling them using (CHP) is presented in [23]. In [24], to reduce the renewable curtailment and energy intensity problem, cryptocurrency mining devices were installed on the generation side of solar and wind farms.

In [25], technical, economic, and environmental analyses for Ethereum mining are proposed by using a grid-connected PV system. This analysis was performed to prevent the illegal increase in the energy consumption of miners in Iran. In [26], to cover renewable energy investment, investment in BTC farms in the vicinity of wind farms, instead of selling electricity to the grid, has been investigated and studied. In [27], an economic framework for evaluating BTC mining in a microgrid considering wind energy, solar energy, and storage has been presented.

D.Energy efficiency

Since new appliances are introduced over time and with the advancement of technology, an increase in residential building energy consumption is observed. Buildings currently account for about 40% of the world's energy consumption, which is expected to reach 50% in 2030 [٢٨]. Also, with the coronavirus outbreak in Wuhan, China, in late December 2019 and its gradual spread around the world to date, the presence of people at home has increased, and this issue has increased energy consumption in residential buildings [٢٩]. Based on the previous content, energy efficiency in residential buildings and greenhouses is a critical issue. Although many energy efficiency programs are economically affordable in the long-run, an investment in energy efficiency is still lower than expected [٣١ ,٣٠]. In this regard, more incentives are required to attract subscribers better. Using cryptocurrency miners in the energy hub as an energy efficiency incentive can help improve subscriber participants in energy efficiency programs and reduce the challenges of supplying cryptocurrency miners.

Energy efficiency programs have the potential to provide the fastest and most economical way to address energy security and environmental and economic challenges. In the same context, introducing smart buildings has become one of the promising strategies to help implement energy efficiency programs [٣٢]. For energy saving and environmental protection, energy labeling has been introduced by the IEA as a specific mechanism of energy efficiency programs to influence energy consumption behavior. To calculate the energy label for the residential building, energy usage intensity (EUI) is introduced. It is used as an indicator to compare the energy consumption of similar buildings positioned in similar weather conditions [٣٣]. To use the energy labeling system, a seven-point structure organized from A as the highest class in terms of energy efficiency to G as the lowest class has been introduced. Energy labeling systems use different methods to increase energy efficiency in buildings, which have been investigated based on building materials [٣٤]. In [٣٥], it has been studied based on the operation condition, while in [٣٦], it is based on the climate zone, and in [٣٧] based on energy efficiency systems. In [٣٨], a new method is proposed to quantify building energy flexibility.

E. Contributions, highlights, and paper structure

In this paper, a rural residential energy hub framework is proposed. The proposed framework is mainly intended for rural areas or small towns with fewer restrictions on allocating greenhouse land. The main contributions of this paper are as follows:

- Modeling a cryptocurrency miner in a rural residential energy hub
- Supplying thermal and electrical greenhouse demand by residential energy hub
- Injecting carbon dioxide produced by CHP/ CCHP into the greenhouse

In Table I, some papers on energy efficiency and energy management are compared with the proposed structure. This paper is organized as follows: In section ٢, the proposed framework is presented as an energy hub in a rural residential building. In section ٣, modeling the proposed structure of an energy hub is given, and numerical results and discussions are provided in section ٤. Finally, in section ٥, the concluding remarks are driven.

II.The Proposed Energy Hub Framework

In this paper, a new structure is introduced for an energy hub: to improve its energy efficiency, increase greenhouse efficiency, reduce investment costs, and enhance the total income of the subscribers. In the proposed framework, a set of components such as electrical energy storage, photovoltaic system, CHP unit, cryptocurrency miner, and agricultural greenhouse are considered in the energy hub (see Fig. 1). A miner produces a considerable amount of heat during the mining process, which can be used for heating in the energy hub. The greenhouse thermal demand will be provided by the thermal power generated by CHP and a miner. Also, in this energy hub, the amount of carbon dioxide (CO2) produced by CHP is injected into the greenhouse for two purposes:

I) reducing greenhouse gas emissions by the energy hub and II) increasing production efficiency in greenhouses. Fig. 2 is a schematic that displays the energy consumption analysis of the proposed energy hub.

In the first step, the optimization process is carried out to minimize the energy costs by considering inputs such as TOU energy tariff and energy demand. After the optimization process for the base case and the proposed cases, the amount of electricity and gas imported from the grid to the energy hub is determined. Then, according to the imported electricity and gas in that case, is analyzed based on the available standards. For cases with greenhouses, specific energy consumption and for greenhouse-free cases, the energy labeling system has been used to analyze energy consumption.

TABLE I

COMPARING THE PROPOSED STRUCTURE WITH PREVIOUS STUDIES

Reference	Type of energy hub	Greenhouse	Miner	PHEV	PV	wind	Fuel cell	Biogas
[5]	industrial	✓	✗	✗	✗	✗	✗	✗
[6]	industrial	✓	✗	✗	✗	✗	✗	✗
[7]	residential	✗	✗	✗	✓	✗	✗	✗
[8]	residential	✗	✗	✓	✓	✗	✗	✗
[9]	residential	✗	✗	✓	✓	✗	✗	✗
[10]	residential	✗	✗	✗	✗	✗	✗	✗
[12]	residential	✗	✗	✗	✓	✓	✗	✗
[14]	residential	✗	✗	✗	✓	✓	✗	✗
[15]	residential	✗	✗	✗	✓	✗	✓	✗
[16]	residential	✗	✗	✗	✓	✓	✓	✗
[17]	industrial	✗	✗	✗	✓	✗	✓	✗
[18]	residential	✗	✗	✗	✓	✓	✓	✗
[19]	industrial	✗	✗	✗	✓	✓	✗	✓
[20]	residential	✗	✗	✗	✓	✗	✗	✓
[22]	industrial	✗	✓	✗	✗	✗	✓	✓
[24]	industrial	✗	✓	✗	✓	✓	✗	✗
[25]	industrial	✗	✗	✗	✓	✗	✗	✗
[26]	industrial	✗	✓	✗	✗	✓	✗	✗
[27]	industrial	✗	✓	✗	✓	✓	✗	✗
Proposed method	residential	✓	✓	✗	✓	✗	✗	✗

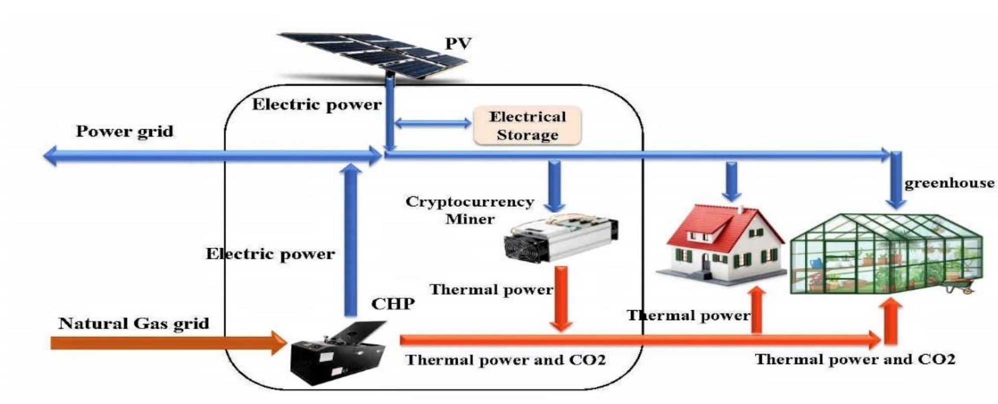

Fig. 1. Proposed Energy Hub Structure

[DOI: 10.61186/joc.17.3.67]

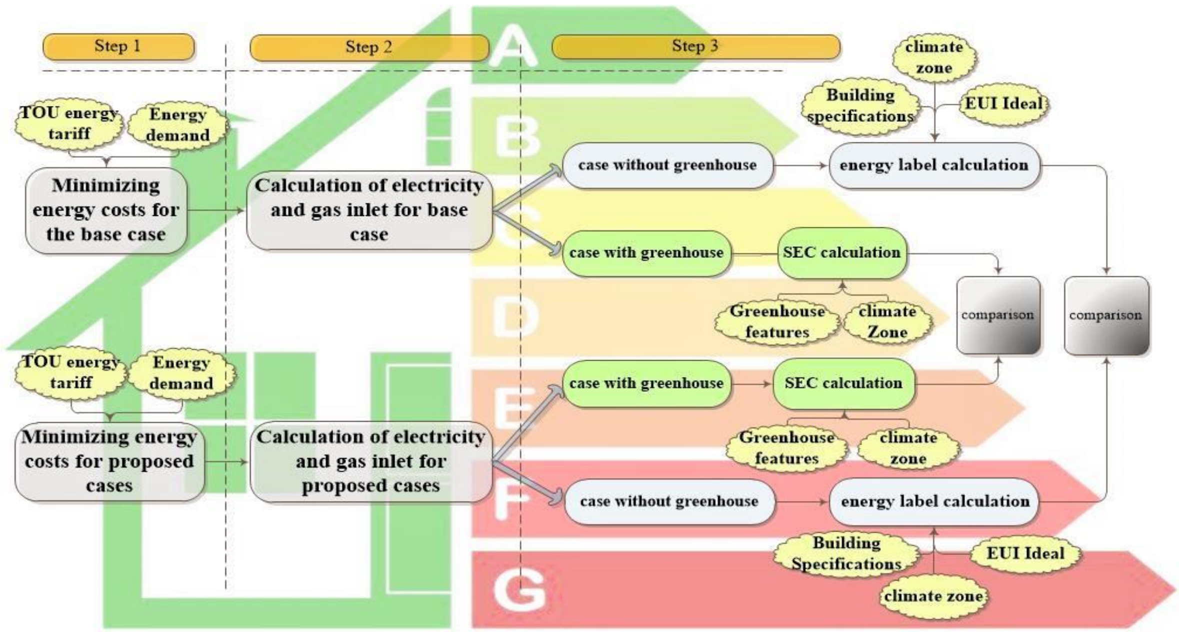

Fig. 2. Schematic of energy consumption analysis method for different cases

After obtaining the specific energy consumption index and the energy labeling index, these values are compared with the base case. If there is an improvement in the amount of these indicators, the relevant cases will receive financial incentives. In the last step, according to the incomes, investment cost, and incentives NPV analysis is done for each case.

III. Mathematical Formulation

A. Optimization model

In the following, the optimization model for the proposed energy hub is provided. In this model, the greenhouse, PV system, electrical storage, cryptocurrency miner, and CHP have been considered. Also, in this model, the heat produced by the miner is recycled and reused:

$$min \sum_{t=1}^{24} \big(C_g(t).G_{in}(t) + C_e(t).(E_{in}(t) - P_{H2G}(t))\big) \quad (1)$$

S.t.

$$H_{CHP}(t) = H_d(t) - H_{miner}(t) + H_{green}(t) \quad (2)$$

$$E_{in}(t) + P_{CHP}(t) + \eta_{dch}.P_{dCH_{batt}}(t) + \eta_{dc}.P_{pv}(t) = E_d(t) + \left(\frac{1}{\eta_{ch}}\right).P_{CH_{batt}}(t) + P_{H2G}(t) + P_{miner}(t) + P_{green}(t) \quad (3)$$

$$(P_{CHP}(t) - P_A) - \left(\frac{P_A - P_B}{H_A - H_B}\right).(H_{CHP}(t) - H_A) \leq 0 \quad (4)$$

$$(P_{CHP}(t) - P_B) - \left(\frac{P_B - P_C}{H_B - H_C}\right).(H_{CHP}(t) - H_B) \geq -\big(1 - I_{CHP}(t)\big).W \quad (5)$$

$$(P_{CHP}(t) - P_C) - \left(\frac{P_C - P_D}{H_C - H_D}\right).(H_{CHP}(t) - H_C) \geq -\big(1 - I_{CHP}(t)\big).W \quad (6)$$

$$P_{CHP_{min}}.I_{CHP}(t) \leq P_{CHP}(t) \leq P_{CHP_{max}}.I_{CHP}(t) \quad (7)$$

$$0 \leq H_{CHP}(t) \leq H_{CHP,MAX}.I_{CHP}(t) \quad (8)$$

$$G_{in}(t) = P_{CHP}(t)/\eta_{eCHP} \quad (9)$$

$$SOC(t) = SOC(t-1) + \eta_{ch}.P_{CH_{batt}}(t) - \frac{P_{dCH_{batt}}(t)}{\eta_{dch}} \quad (10)$$

$$0 \leq P_{CH_{batt}}(t) \leq I_{ch}(t).P_{ch_{max}} \quad (11)$$

$$0 \leq P_{dCH_{batt}}(t) \leq I_{dch}(t).P_{dch_{max}} \quad (12)$$

$$I_{ch}(t) + I_{dch}(t) \leq 1 \quad (13)$$

$$SOC(t) \leq E_{batt_{max}} \quad (14)$$

The main objective of the proposed optimization model is minimizing the cost of energy based on the imported energy from the grid, which is expressed in Eq. (1). This objective function is subjected to a set of constraints. Eq. (2) shows the heat generated by the CHP unit ($H_{CHP}(t)$) that should meet all thermal needs, including the thermal demand of the residential building ($H_d(t)$) and the thermal demand of the greenhouse ($H_{green}(t)$) per hour. In addition, the heat generated by the miner ($H_{miner}(t)$) also provides some part of the heat demand in the energy hub .According to (3), the total

[DOI: 10.61186/joc.17.3.67]

electrical energy generated by the CHP unit ($P_{CHP}(t)$) and the electricity imported from the grid ($E_{in}(t)$), and the solar system power should meet all electrical demands, including the electrical demand of the residential building ($E_d(t)$), the miner power consumption ($P_{miner}(t)$), the greenhouse electrical demand ($P_{green}(t)$) per hour.

Equations (4)-(6) determine the operating region of the CHP unit, where the indicators A, B, C, and D, are the four boundary points of the possible operational zone of the CHP. Thermal energy and electricity generated by CHP should be allowed at the minimum and maximum magnitudes provided in (7) -(8). In these equations, ($I_{CHP}(t)$) is the binary variable representing the CHP status. The natural gas imported ($G_{in}(t)$) into the CHP unit is calculated by (9). The storage constraints are expressed in (10)-(13). In (14), the acceptable amount of energy in the energy storage system is addressed.

B. Energy label of the residential building

After calculating the electricity and gas input to the energy hub, the total energy input to the energy hub ($QT(d)$) is calculated based on [9]. To calculate the EUI (energy usage intensity), ($Q_T(d)$) must be executed for all days of the year .Therefore, the actual EUI is obtained by (15). S is the residential building area (m^2).

$$EUI_{actual} = \frac{\sum_{d=1}^{365} Q_T(d)}{S} \tag{15}$$

The energy label index is the ratio of real EUI to ideal EUI expressed by (١٦).

$$R = \frac{EUI_{actual}}{EUI_{ideal}} \tag{16}$$

According to the climatic zone and global standards, the ideal EUI is considered 156 (kWh/m^2/year).

C. Specific energy consumption

Specific energy consumption has been used to calculate greenhouse consumption and compare the effects of the proposed structure on greenhouse consumption. Specific energy consumption is the energy consumed per unit area. It is a global benchmark that has been adopted to compare the energy consumption of different greenhouses.

- Calculating thermal specific energy consumption (SEC_{th})

The thermal specific energy consumption is in MJ/m2 and calculated by (17).

$$SEC_{th} = \frac{FC.HV}{S_G} \tag{17}$$

FC, is the quantity of fuel energy consumption (Natural Gas(M3)), and HV is the heating value of the energy carrier. S_G is the greenhouse area in square meters. In this paper, natural gas is considered as fuel, and the heating value of each cubic meter of natural gas equals 35.9 MJ.

- Calculating the electrical specific energy consumption (SEC_e)

SEC_e is in kilowatt-hours per square meter and calculated by (18).

$$SEC_e = \frac{EE}{SG} \tag{18}$$

That EE is the electrical energy consumption in kilowatt-hours, and SG is the greenhouse area per square meter. Total specific energy consumption (SEC_{tot}) is in MJ/m^2 and it is calculated by (19).

$$SEC_{tot} = SEC_{th} + 3.6.SEC_e \tag{19}$$

SEC_e is in kWh/m^2, and 3.6 is the conversion coefficient from kilowatt-hour to mega-joules. If electrical energy is received from the grid, SEC_e (in (19)) should be converted to the equivalent of primary energy according to the average efficiency of the country's generation and distribution network.

IV. Case Study

The proposed approach has been applied to a residential building energy hub with real data, including 15 cases to investigate the effectiveness of the proposed structure. In this paper, three base cases are considered. By adding additional elements to the base case, the effect of the elements is investigated and compared with the base case.

A. Data

A 5 kW PV system and electrical storage with 4.8 kWh capacity are considered in this paper. Fig. 3 displays the power generated by the PV system at different times of the day. Two CHP units with 1 kW and 2 kW rate power are employed. The cryptocurrency miner for this energy hub is an Ethereum miner (Antminer E3) with 800 W rated power consumption and 180 mh processing power. To better check the efficiency and performance of the proposed structure, the highest daily consumption of the house and greenhouse during the one year has been used for this paper Fig. 4 shows the maximum daily electrical demand of the rural residential building and greenhouse, while Fig. 5 shows the maximum daily thermal demand for the rural residential building and greenhouse.

The greenhouse intended for this energy hub is a cucumber greenhouse with a 200 m2 area. Electricity and gas tariffs in different periods of the day and some additional required parameters are displayed in Table II. Other information about the rural residential building and the greenhouse is shown in Table III. After calculating the energy label index (R), the building energy label is specified using Table IV.

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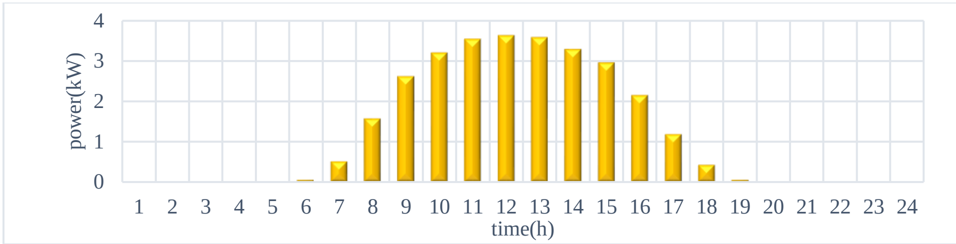

Fig. 3. Power generated by PV during the day

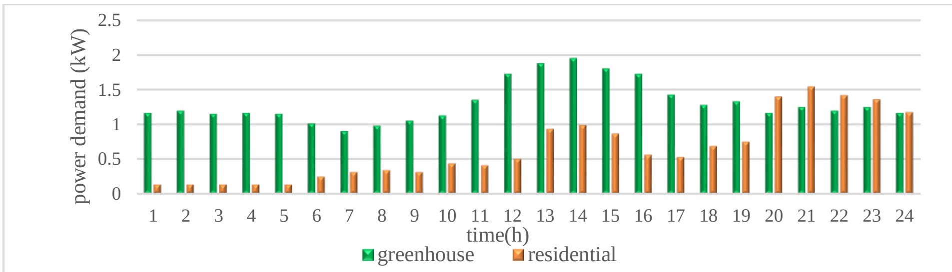

Fig. 4. electrical demand of a rural residential building and a greenhouse

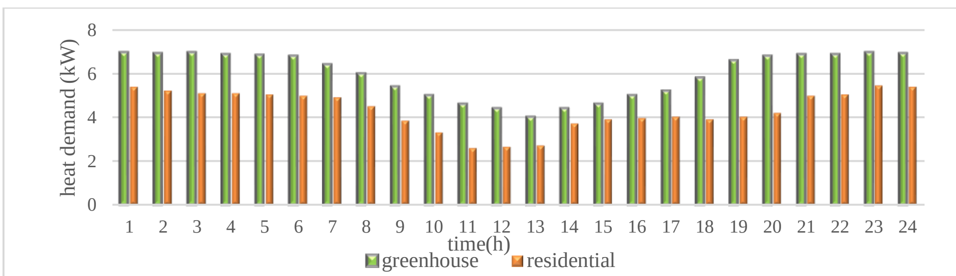

Fig. 5. Heat demand in a rural residential building and greenhouse

TABLE II

TOU TARIFFS AND ENERGY USAGE COEFFICIENT

		Valley	Off-peak	Peak
Gas	Time classification	7:00 to 13:00	13:00 to 20:00	20:00 to 7:00
	Energy usage coefficients($\beta_1 - \beta_3$)	0.7	1	1.3
	TOU tariff- $C_g(t)$ ($/kWh)	0.04	0.055	0.08
Electricity	Time classification	0:00 to 8:00	8:00 to 13:00 and 15:00 to 20:00	13:00 to 15:00 and 20:00 to 00:00
	Energy usage coefficients($\alpha_1 - \alpha_3$)	0.8	1	1.2
	TOU tariff- $C_e(t)$ ($/kWh)	0.15	0.2	0.3

TABLE III

RESIDENTIAL BUILDING AND THE GREENHOUSE DATA

Specifications	Greenhouse	Rural residential building
Country & Province	Iran, Kerman Province, Golzar Town	Iran, Kerman Province, Golzar City
Latitude	29.7108 degrees north	29.7108 degrees north
Longitude	57.0408 degrees E	57.0408 degrees E
Weather Zone	Cold Winter / Hot Summer	Cold Winter / Hot Summer
Number of people	*NA	5
Total area (m^2)	200	100
Energy supply system	The Photovoltaic system, Gas grid, Electrical storage, CHP, Power grid	
Product	Cucumber	--------------------

*NA: NOT APPLICABLE

[DOI: 10.61186/joc.17.3.67]

TABLE IV
ENERGY LABELS FOR RESIDENTIAL BUILDINGS [۹]

R-value	Energy label
R≤1	A
1<R≤2.1	B
2.1<R≤3	C
3<R≤3.8	D
3.8<R≤4.5	E
4.5<R≤5.1	F
5.1<R≤5.5	G
5.5<R	No energy labels

In this paper, the optimization problem aims to determine the amount of electricity and gas inlet to the energy hub of a rural residential building in the 24-hour time horizon. It is formulated as mixed-integer linear programming (MILP), considering 15 cases. In each stage, a component is added to the energy hub to determine the changes in fuel consumption compared to the previous case (base case). The description of the considered cases is given in Table V. To solve the optimization problem, the CPLEX solver is used in the GAMS environment. For calculations, a system with 1.2 GHz CPU and 8 GB RAM is employed.

B. Results and analysis

In this section, different cases are evaluated on the impact of energy efficiency .Cases 1 to 11 are compared based on the energy efficiency index. Cases 12 to 15 are compared due to the existence of greenhouses. These cases are compared based on specific energy consumption.

The cost function value, SEC, and energy label index for different cases are given in Table VI. According to the obtained results, case 4 has the most improvement (52%) compared to the base case. Also, case 3, with a 97% drop, has the most negative impact on the R index. The existence of electrical storage reduced the fuel cost and increased the R-index in case 5. However, the miner heat recovery has reduced the R-index by 7% compared to case 8.

On the other hand, recycling miner heat in case 11 increases the R-index by 0.24% compared to the previous case. Table VI displays R values for different cases . Cases 13 to 15 are compared in energy consumption, whereas case 14 (using CHP to provide greenhouse thermal power) will improve electrical specific energy consumption ($SECe$) by 72% .In addition, in Case 14 total specific energy consumption (SEC_{tot}) improved by 3.3%. Also, by applying the proposed structure, in case 15, $SECe$ and SEC_{tot} are improved by 82.7% and 6.2%, respectively.

TABLE V
DESCRIPTION OF 15 CASES

No	Case description
1	residential building feeding from the grid (base case1)
2	residential building + CHP (1 kW)
3	residential building + CHP (2 kW)
4	residential building + PV (5 kW)
5	residential building + PV (5 kW) + electric storage (4.8 kW)
6	residential building + CHP (2 kW) + PV (5 kW)
7	residential building + CHP (2 kW) + PV (5 kW) + electrical storage (4.8 kW)
8	(residential building + cryptocurrency miner (feeding from the grid)) (base case2)
9	residential building + cryptocurrency miner (feeding from the grid + recycling miner heat)
10	residential building + CHP (2 kW) + PV (5 kW) + electric storage (4.8 kW) + cryptocurrency miner
11	residential building + CHP (2 kW) + PV (5 kW) + electric storage (4.8 kW) + cryptocurrency miner + (recycling miner heat)
12	residential building + CHP (2 kW) + PV (5 kW) + electric storage (4.8 kW) cryptocurrency miner + greenhouse (200 m2)
13	(residential building + greenhouse (feeding from the grid)) (base case 3)
14	residential building + CHP (2 kW) + agricultural products greenhouse
15	residential building + CHP (2 kW) + PV (5 kW) + electric storage system + agricultural greenhouse (200 m2)

[DOI: 10.61186/joc.17.3.67]

TABLE VI

R-INDEX, SECTOT, AND DAILY ENERGY COST FOR 15 DIFFERENT CASES

No	Energy label index(R)	SEC_{tot}**(MJ/m^2)	Daily Energy cost ($)*
1	4.5725	NA	5.0092
2	5.55	NA	2.28
3	9.92	NA	-0.373
4	2.17	NA	-1.089
5	2.21	NA	-1.275
6	8.6	NA	-6.47
7	8.4	NA	-6.65
8	6.23	NA	9.12
9	5.79	NA	8.97
10	9.15	NA	-2.53
11	9.17	NA	-2.55
12	NA	NA	4.5
13	NA	2749.47	13.75
14	NA	2658.58	6.68
15	NA	2578.627	0.4202

*THE NEGATIVE SIGN REPRESENTS COVERING COSTS AND GENERATING REVENUE (WHEN SELLING ELECTRICITY TO THE GRID)
** SPECIFIC ENERGY CONSUMPTION
NA: NOT APPLICABLE

According to [۳۹], in Table VII, the proposed structure could increase greenhouse production by 23%. In case 15, which is considered as a sample, annually, 442.8 MMBTU of energy is consumed by the CHP unit, which produces 23.47 tons of CO2. By injecting this CO2 into the greenhouse, its release into the environment is prevented. Also, the proposed approach eliminates the need to purchase CO2 production equipment (which is used to increase the efficiency of the greenhouse).

TABLE VII

THE EFFECT OF INCREASING CO2 CONCENTRATION ON INCREASING PRODUCTS [۳۹]

Product Name	Increasing CO_2 concentration to	Increase product (%)
Lettuce	1600 ppm	31
Tomatoes	1000 ppm	48
Cucumber	1000 ppm	23

In this paper, the interest rate is 16% for NPV analysis, and the annual rate of energy price increase equals 10%. To determine the partial effects of different elements, assume that the consumption pattern is constant. Also, the highest amount of daily energy consumption (the worst case of consumption) is considered for the whole year. PV production power value is regarded as its average production value. With these assumptions, the revenue of each element is calculated and considered in the economic analysis. The net income and investment costs for different cases are presented in Table VIII.

As specified in Table VI, case 7 has the highest improvement (132%) in energy cost compared to the base case 1, which is due to the energy production and performance of the existing elements (CHP (2 kW) + PV (5 kW) + electrical storage (4.8 kWh) in the energy hub. The lowest improvement is related to case 2 (CHP 1 kW). The highest energy cost is related to case 13 due to the complete feeding of the greenhouse and residential building from the grid.

The addition of electrical storage in case 5 improves energy cost by ۱۷% compared to case 4, and in case 7 improves the energy cost by 2.7% compared to Case 6. Miner heat recovery in case 9 compared to case 8 has resulted in a 1.6% improvement in energy cost. Also, feeding the greenhouse with an energy hub has a positive impact on the cost function. In case 14, the cost function value is improved by 50%. Also, in case 15, the energy cost is enhanced by 97% compared to case 13 (base case 3).

Net Present Value (NPV) analysis has been performed for different cases in the 5-year time horizon. The study is based on tariffs intended for electricity and gas, current investment costs for each case, and the Ethereum price when performing this research. The annual increase in the energy price rate is considered to be 10%. Also, the shelf life of batteries is three years, and the cost of switching them is $1069. The revenue from the cryptocurrency miner is calculated based on the Ethereum price and Ethereum network difficulty when writing the paper.

[DOI: 10.61186/joc.17.3.67]

TABLE VIII
THE NET INCOME AND THE INVESTMENT COST FOR DIFFERENT CASES

	Net income*					
Case number	year 1($)	year 2($)	year 3($)	year 4($)	year 5($)	total investment ($)
2	996	1095.6	1205.16	1325.676	1458.244	2320
3	1964.5	2160.95	2377.045	2614.75	2876.224	4640
4	3108.78	3419.028	3761.62	4137.78	4551.55	4500
5	3176.6	3493.63	3843.683	4228.052	4650.851	5562
6	4189.9	4608.89	5069.779	5576.757	6134.433	9140
7	4255.6	4681.16	4087.276	5664.204	6230.624	10202
8	1190	857.2	491.12	88.432	-354.525	800
9	1244	916.6	556.46	160.306	-275.463	800
10	5441.45	5985.595	5522.155	7242.57	7966.827	11002
11	5448.75	5993.625	6592.988	6190.286	7977.515	11002
12	5582	6140.2	6754.22	7429.642	8172.606	15402
13	-2701.45	-3202.6	-3753.85	-4360.24	-5027.26	5200
14	268	294.8	324.28	356.708	392.3788	9040
15	2852.73	2867.403	1821.543	2901.298	2920.827	14602

*THE NEGATIVE SIGN INDICATES THAT COSTS ARE GREATER THAN REVENUES IN THAT YEAR

As shown in Fig 6, case 13 (feeding house and greenhouse with grid), due to high energy consumption and increased investment cost, has the lowest NPV .Also, the proposed structure (cases 14 and 15) has a positive impact on the NPV compared to case 13 (base case 3). This improvement is due to the reduction of energy costs and investment costs and the increase in greenhouse crops.

Case 11 (feeding miner and residential building with energy hub) has the highest NPV. Even though cases 4 and 5 have received direct financial incentives due to improved energy labels of the building, their NPVs are far from case 11. As can be seen in Fig 6, the application of the proposed structure in cases 11 and 15 has greatly improved the NPV value.

As observed in the above analysis of this section, different output results have been analyzed in this paper such as reducing CO_2 emissions, increasing greenhouse products, reducing energy costs, and increasing economic efficiency. According to Table IX, none of the previous related studies provide such a comprehensive analysis.

To better check the proposed framework, a sensitivity analysis has been performed for case 15. This analysis was carried out with five changes in the amount of demand. Afterward, specific energy consumption (SEC) was calculated for each of the demands, see Fig 7 and Fig 8. In the first step, a 50% reduction was made in the actual amount, and in the second step, the actual value is applied. In the subsequent stages, 100% was added to the demand. The results of this analysis show that with the decrease in demand, a lower percentage in the improvement of SECtot is observed. Also, with the increase in the electrical demand, it is observed that the proposed framework has a better effect on reducing energy consumption, see Table X.

V. CONCLUSIONS

Adding greenhouses to the energy hub and feeding the greenhouse with the energy hub reduces the initial costs of establishing a greenhouse, such as purchasing heating equipment. Also, if only CHP is used to feed the greenhouse, we saw a 50% cost reduction, and when using all elements of the proposed structure, the energy cost reduction is 97%.

The results of economic analysis for different cases indicate that the use of the proposed structure (supply cryptocurrency miner with energy hub) has a higher NPV value and higher economic efficiency than other cases. In addition, applying the proposed structure depending on the type of greenhouse product may lead to different results because different crops react differently to the increase in CO_2 concentration.

Because in this paper, cucumber is considered for the greenhouse, the proposed structure can increase the products by 23%. In addition, the proposed structure can prevent the release of 23 tons of CO_2 into the environment annually. Furthermore, the results indicate that miner heat recovery has a positive impact on cost function and energy label index (when entirely feeding

[DOI: 10.61186/joc.17.3.67]

gas and electricity from the grid). On the other hand, when CHP is present in the energy hub recycling miner heat has no favorable effect on the energy label index. The results show the effectiveness and profitability of the proposed structure in terms of energy consumption and greenhouse gas emissions. Also, the proposed approach positively impacts greenhouse products and NPV. As a future work, the effect of cryptocurrency miner type based on its mining type (Ethereum, bitcoin, etc) on the economic profitability of the developed energy hub can be studied. Also, revenues that can be obtained by the agricultural greenhouse and cryptocurrency miner can increase the economic profitability of the proposed framework that can be included in future models.

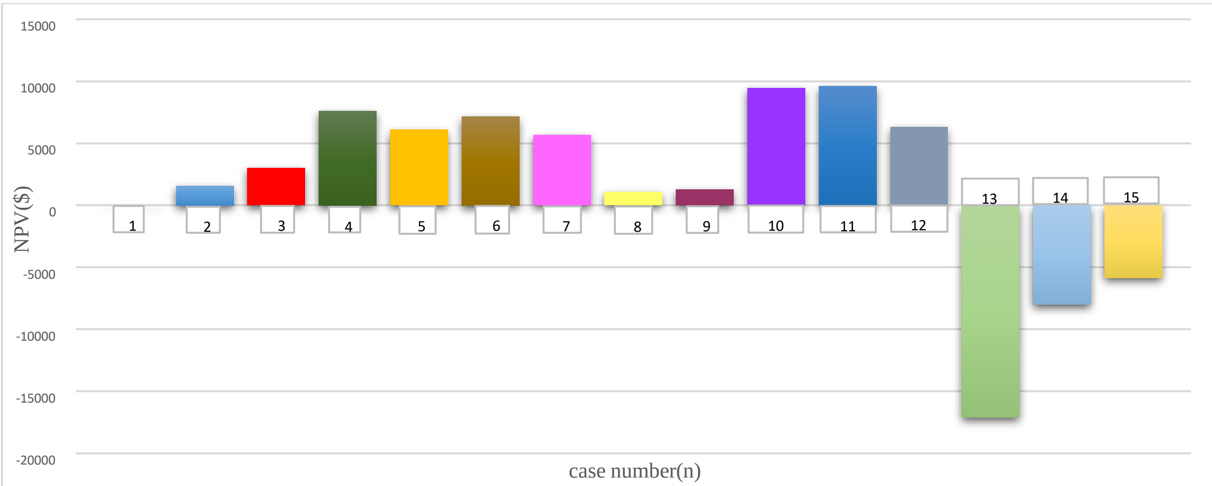

Fig. 6. NPV for different cases

TABLE IX
THE OUTPUT RESULTS ANALYZED IN THIS PAPER IN COMPARISON TO THE PREVIOUS STUDIES

REFERENCE	THE TYPE OF ENERGY HUB	REDUCING CO2 EMISSIONS	INCREASE GREENHOUSE PRODUCTS	REDUCING ENERGY COSTS	INCREASING ECONOMIC EFFICIENCY
[5]	INDUSTRIAL	✗	✓	✗	✓
[6]	INDUSTRIAL	✗	✗	✓	✗
[12]	RESIDENTIAL	✗	✗	✓	✗
[14]	RESIDENTIAL	✓	✗	✓	✗
[15]	RESIDENTIAL	✓	✗	✓	✗
[18]	RESIDENTIAL	✓	✗	✓	✗
[19]	INDUSTRIAL	✗	✗	✓	✗
[22]	INDUSTRIAL	✗	✗	✗	✓
[24]	INDUSTRIAL	✗	✗	✗	✓
[25]	INDUSTRIAL	✓	✗	✗	✓
[26]	INDUSTRIAL	✗	✗	✗	✓
THE PROPOSED APPROACH	RESIDENTIAL	✓	✓	✓	✓

[DOI: 10.61186/joc.17.3.67]

Fig. 7. Changes of SECE with the demand changes (for the proposed structure)

Fig. 8. Changes of SECtot with the demand changes (for the proposed structure)

TABLE X
SEC AND TOTAL IMPROVEMENT VALUE FOR CHANGES IN ELECTRIC DEMAND

Power demand		50%	100%	200%	300%	400%
Proposed structure	SECe	3.422483	9.7966	26.14008	46.52898	71.4962
	SECth	2448.04	2448.136	2448.04	2448.04	2448.04
	SECtot	2460.36	2483.404	2542.144	2615.544	2705.426
Grid feeding	SECe	37.81589	56.87357	86.07357	115.2736	144.4736
	SECth	1991.915	1991.915	1991.915	1991.915	1991.915
	SECtot	2495.623	2749.471	3138.415	3527.359	3916.303
Total Improvement (%)		1.41	9.6	18.9	25.8	30.9

[DOI: 10.61186/joc.17.3.67]

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