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Optimizing the size of the hybrid power and heat generation system during COVID-19 crisis (case study: Italy)

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ABSTRACT

The COVID-19 pandemic has caused more than 2.2 million deaths worldwide. The consequences of this disease are expected to continue. The COVID-19 pandemic has affected the global economy, demand for goods and services, and labor. This deadly virus has affected the energy demand in various sectors, the structure of energy production and especially renewable energy. Although judging the future of renewable energy requires a broader perspective, it is clear that the share of renewable energy in electricity generation, heating and energy policies must change after the COVID-19 pandemic. In this study, the optimal share of energy resources in Italy was calculated using the particle swarm optimization (PSO) algorithm and considering the changes in the energy system, energy demand and prices during the quarantine period.

Current conditions and declining fossil fuel prices have led investors to reduce their investment in clean energy, and the amount of investment in renewable energy in 2020 has decreased by about 20% compared to the same period last year. The results of this study show that despite the ubiquitous limitations of COVID-19 for renewable energy, this period is a good opportunity to expand and invest in clean energy due to the increase in the share of electricity demand and domestic heating and the reduction of energy consumption in the industrial sector (Especially solar energy).

1. Introduction

Nowadays, growth of energy demand and diminution in fuel resources have led to increase in prices and by burning them, people around the world have faced lots of environmental problems such as air pollution. Therefore, finding a sustainable and guaranteed way to provide replaceable sources of energy not only for the current generation but also for the future one, is a global challenge. The use of renewable energies such as wind, solar energy and biomass is getting strongly pervasive. COVID-19 pandemic in 2020 can possibly change the optimize combination of consumption and production in industrial units [1].

During COVID-19 pandemic, almost all the governments made decisions without any reliable data or considering the consequences in order to control the crisis. A significant drop was seen in energy consumption. These measurements have exceeded expectations and raised the hopes of using renewable resources prior to the previous plans. Due to the restrictions imposed on business activities, the energy consumption in some areas dropped dramatically. This long-term situation has changed the lifestyle all around the world and switched the projects to out-sourcing form which has led to an increase in the domestic demand load; although, the business and manufacturing demand load has been reduced. This challenging situation has caused a lot of technical and economical problems in the power sector.

According to the International Energy Agency, the global demand has decreased about 3.8% in the first 4 months of 2020 compared to the previous year. This organization also claimed that half of the population around the world who are participant in 60 percent of global are affected by lockdown. Also, the energy consumption pattern has changed among them due to the restrictions. International Energy Agency has also predicted that global demand of energy will drop by 6% which is 7 times higher than 2008 financial crisis and conflicts with the rise of power demand in the last 5 years [2]. Follow the trend in the Fig. 1. Consumption of thermal renewable energy has decreased in 2020. It is expected that the industrial sector consumes less thermal renewable energy because of the decline in industrial, constructions and business activities. Furthermore, low oil and gas prices have recently affected competitive fuel prices and renewable technologies. Most of the planned investments in this area are postponed or canceled due to the lack of
strong and supporting politics. Almost all of the activities in this area have faced lots of basic problems such as applying restrictions on people and goods or cutting the supply-chain of equipment and machinery. However, the most important effect on investment in 2020, especially on oil, originated from the diminution in income due to the drop in prices, demands and also uncertain future of these commodities.

In Fig. 2 the changes in energy investments is shown. Corona virus spread made many of photovoltaic and conversion plans closed in china and vanished the expectation of decrease in the project prices in the first 4 months of 2020. As corona virus has infected the majority of the United States’ population, the demand of new solar energy equipment appeared to be less than ever. Coal and natural gas prices have fallen less than crude oil’s which has decreased about 65% since January 2020. Crude oil is mainly used for transportation, but coal and natural gas are usually burned to produce electricity and industrial purposes so in comparison with crude oil, limitations has lightly affected coal and natural gas demand.

Fig. 3 has illustrated the oil price during lockdown. A significant drop in Natural gas and coal demand was seen. The reduction in industrial activities and electricity consumption due to the recent restrictions and also exceptionally warm winters caused a declining demand in early 2020. According to the International Energy Agency, electricity energy demand during lockdown has fallen by at least 15% in major economies including France, Italy, Spain, and the United Kingdom. On the other hand, the fossil fuels and renewable energies have enhanced their percentage in the energy demand chart in the first 4 months of 2020.

These increments are partially the result of running new wind and solar facilities. International Energy Agency has also confirmed the climb of renewable energy demand in 2020. The price chart of Chinese-made photovoltaic panels is shown in Fig. 4. In Italy, the lockdown policy was performed in two phases; first one was started in the northern part of the country on March 8, 2020, and then extended to the whole nation on March 10, 2020. The quarantine clearly changed the electricity consumption pattern in this country. In Italy, the highest amounts of demand and consumption during lockdown has been compared to those of the previous year [5]. The peak dropped by 6–10% on the weekends and by 18–22% on the other days. We should also consider that the peak load decreased by approximately 15% after the first week of manufactures being closed.

Based on previous studies, quarantine has resulted in a change of electricity consumption pattern around the world by decreasing it during pandemic [1,6,7] Norouzi and colleagues [8] used an artificial neural network model to estimate the elasticity of oil and electricity demand in China; This paper is based on the gross domestic products and also the number of people infected by corona virus, but the exact amount of electricity load was not considered. Ruiz and colleagues [9] found an increase in the electricity consumption in China which seemed to be the result of long-term national quarantine and health-care system’s high demand. The situations in the other parts of the world like USA, Canada [1,10–12] Brazil [13], and Europe [14–17] were the same (See Fig. 5).

Werth et al. [16] have investigated the impact of quarantine and limitations on electrical load, generation, and transmission in 16 European countries. Using the indices provided by the Oxford COVID-19 government response tracker it is obvious that Strict quarantine regulations are correlated with the load decrease. Then, the European network was analyzed in order to evaluate how to balance the load drop with changes in production and transmission patterns. The quarantine period in 2020 was compared with the same time interval of previous years, and the annual variation was calculated using a temporary statistical technique. As a result, it was found that production in most countries was affected by a significant drop in the load. In general, nuclear, fossil coal and gas production has declined in favor of renewable energy and in some countries, fossil gas. Besides, intermittent renewable production increased in most countries without presenting any exceptional limits.

The main purpose of this study is to move toward an integrated and reliable system during COVID-19 crisis and the global energy situation after pandemic and minimizing the expenditures is the optimum performance of this system. This means optimizing the size of the hybrid power and heat generation system, taking into account changes in demand and prices in production and consumption in Italy. Thermal power plant, wind turbine or photovoltaic systems are the suggested microgrid and in this study, the optimization is based on the microgrid size. The investigated costs in this study include investment costs, maintenance costs, emissions costs, fuel costs and also the cost of purchasing power from the network.
2. Methodology

2.1. Climate data collection and processing

Wind and solar energy data as well as ambient temperature over a period of one year are required to process and simulate the present project. The pattern of changes of the required data for the present study has been obtained through extracting wind, solar, and ambient temperature data from the NASA site at the studied area. Fig. 6 illustrate the monthly solar irradiation, ambient temperature and wind speed data profile in Italy.

2.2. Electrical load and natural gas demand modeling

The electric load and the monthly average load profile are plotted by Homer software and shown in Fig. 7. The rate of decline in natural gas...
consumption in some EU countries and the United States is shown in Fig. 8. The generation capacity in Italy consists of renewable energy sources and thermal generation and shown in Fig. 9, by law since 1987 and about 15% of the electricity is imported from abroad.

2.3. Wind power generation model

The wind turbine output power can be calculated using the wind data and considering the wind turbine power curve relative to its speed. Wind speed is an arbitrary variable which takes into account the

Fig. 4. Price of photovoltaic panels [5].

Fig. 5. The share of renewables in electricity demand [18].
nonlinear values to the turbine power output. As the speed varies with height of turbine, the wind speed measured in a cup anemometer at a certain height will be converted into a hub with a reference height.

\[
v_2 = \left( \frac{h_2}{h_1} \right)^\alpha \quad (1)
\]

where, \( v_2 \) is the velocity at the height of \( h_2 \), \( v_1 \) is the velocity at the reference height \( h_1 \), and \( \alpha \) is the friction coefficient. In fact, \( \alpha \) is the power factor of wind direction changes as a function of parameters such as wind speed, ground type, height, temperature, day time and year. The most common method of defining \( \alpha \) is based on different area types. This value is equal to one-seventh for open areas. The output power of wind turbines can be approximately obtained from the equation 2:

\[
P_{\text{wind}}^\text{r} = \begin{cases} 0 & V < V_{\text{cut-in}} \\ V \left( \frac{P_{\text{wind}}^\text{r}}{V_{\text{cut-out}}} - \frac{V^3}{V_{\text{cut-in}}^3} \right) & V_{\text{cut-in}} \leq V \leq V_{\text{cut-out}} \\ P_{\text{wind}}^\text{r} & V_{\text{cut-out}} < V \leq V_{\text{rate}} \end{cases}
\]

(2)

where, \( P_{\text{wind}}^\text{r} \) is the nominal power, \( V \) is the current wind speed at current times, \( V_{\text{cut-out}} \), \( V_{\text{rate}} \), \( V_{\text{cut-in}} \) indicate low cut-off speed, nominal speed and high cut-off speed, respectively [21].

Modeling the output power of a photovoltaic system...
Fig. 8. The rate of reduction of natural gas consumption [19].

Fig. 9. Italian power capacity [20].
Based on solar irradiation, the power output of the photovoltaic panels can be calculated using the solar irradiation Eq. (3).

$$P_{PV}^e = \frac{P_{N_{PV}}}{G_{ref}} \times \left[ 1 + k_r \times \left( T_{amb} + (0.0256 \times G) - T_{ref} \right) \right]$$  \hspace{1cm} (3)$$

Where $P_{PV}^e$ is the output power of the photovoltaic system, $P_{N_{PV}}$ is the rated power of the system, $P_{N_{PV}}$ is solar irradiation per hour (in W/m²), and $G_{ref}$ is 1000 W/m². Also, $T_{ref}$, the reference temperature, is equal to 25°C, $k_r$ is $-3.3 \times 10^{10}$ and $T_{amb}$ is the ambient temperature. [22]

2.4. Objective function

As mentioned before, different objective functions can be assigned to an energy hub. In a comprehensive study of an energy system, the system is usually evaluated from technical, economic, environmental and reliability aspects. The proposed objective function in this research is to minimize the system cost.

2.5. Costs of the system

In this study, the costs of the system include investment, operation and maintenance (O&M) costs, and replacement costs. Renewable energy systems have no cost for fuel and the associated O&M costs are very low. However, the investment costs are usually very high in these systems due to the high cost of the technologies used. In this study, the annual cost of the system includes the cost of purchasing electricity and the cost due to the emission of greenhouse gasses [23, 24].

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The system costs are briefly described in Table 1.

### Table 1. The cost values of system components

| Costs       | Expression                                                                 |
|-------------|----------------------------------------------------------------------------|
| Cost of capital investment | $C_{cap} = \sum_{tech} \max(cap_{tech}) \times c_{cap_{tech}} \times \frac{R}{(1+R)^n}$  \hspace{1cm} (5) |
| Cost of fuel | $C_{fuel} = \sum_{tech} \sum_{tech} P_{tech} \times \frac{F_{fuel,tech} \times (1 + ND)}{\eta_{tech}}$  \hspace{1cm} (6) |
| Cost of electricity | $C_{elec} = \sum_{tech} \sum_{tech} P_{tech} \times \frac{F_{elec,tech}}{\eta_{tech}} \times ND$  \hspace{1cm} (7) |
| Cost of operation and maintenance | $C_{om} = \sum_{tech} \max(cap_{tech}) \times fr \times \frac{R}{(1+R)^n}$  \hspace{1cm} (8) |
| Cost of emission | $C_{emission} = \sum_{tech} \max(cap_{tech}) \times (Total fuel consumption) \times ND$  \hspace{1cm} (9) |
| Capital revenue rate | $nlife$  \hspace{1cm} \( P_{tech} \): energy hub input energy  \hspace{1cm} \( F_{tech} \): electricity price per Kwh  \hspace{1cm} \( ND \): number of days  \hspace{1cm} \( R \): capital revenue rate  \hspace{1cm} \( C_{cap_{tech}} \): technology capacity  \hspace{1cm} \( \eta_{tech} \): technology revenue  \hspace{1cm} \( fr \): percent of M&O to capital cost  \hspace{1cm} \( C_{emission} \): Emission cost per Kwh energy  \hspace{1cm} \( ND \): number of days |
3. Results

In this study, it’s obvious that despite the increasing solar energy-production cost and the decreasing oil price, still, the best system to respond to the electricity demand is solar. However, because of thermal demand, Thermal power plants also must be in progress. It should be noted that according to the Corona era, the initial cost of the heating system is less than the solar power plant, but considering the cost of emission of this system and the price of fossil fuels, the solar system is preferred.

During the coronavirus pandemic, some policies should be adopted to adjust the price of solar energy and the imbalances between them and fossil fuels. As is shown in Figs. 10 and 11, the optimal composition of the solar, wind, and fossil energy systems change before and after corona-virus disease. It can be said that according to the previous cost-benefit analysis, the amount of electrical energy production through photovoltaic panels is a constant value despite the existing limitations.

However, considering the drop in thermal and electricity demand for the proportion of photovoltaic panels has been increased (Fig. 12). As mentioned before, the reduction in the price of fossil fuels has not been enough to make energy production through the consumption of fossil fuels (oil or natural gas) preferable to solar energy production.

4. Conclusion

Indicators show that the COVID-19 is pushing the global economy into a larger recession than the 2008 recession. The negative impact of the COVID-19 on the economy first appeared in China, but later it became clear that China is not the only economic victim of the COVID-19 and the whole world will be affected. The coronavirus spread has shut down most of the European economy. People and factories in Italy are under forced lockdown. Obviously, the lockdown and the forced closure of businesses and educational institutions around the world have significantly affected energy consumption, carbon dioxide emissions,
the green economy, and renewable energy. The cessation of commercial and industrial activities and restrictions in the transportation sector has led to a decrease in energy demand. On the other hand, housing proportion has led to an increase in energy consumption, but due to smaller changes in comparison with electricity demand and industrial heating, the total amount of energy demand has decreased.

In most of the EU countries, including Italy, solar and wind conditions are suitable for optimal energy production. Although the prices of photovoltaic panels and wind turbines have risen due to the decline of production, the current installed capacity can provide a significant amount of electricity demand. Due to the COVID-19 pandemic and the lockdown of Europe, not only the installation of the facilities related to the new generation of renewable electricity has faced lack of labor, but also the advantage of renewable energy is not directly affected by global fluctuating fuel and fossil prices and lack of labor and operating costs. Therefore, due to the reduction in the energy demand, the capacity to generate electricity through thermal power plants should be reduced, and as a result, according to the findings of this study, the proportion of renewable energy production will increase. For two main reasons, renewable energy was more resistant to shrinkage than fossil fuels during the coronavirus outbreak. Renewable energy can get connected to the grid more easily and is also before fossil energy sources. Buying renewable energy at an equal price is much preferred.

These are all happening while the decline of incomes in the year 2020 can negatively affect the investment in energy in the next few years. The current situation has led to a decrease in prices in most of the markets. Meanwhile, the reduction in the energy value in the European Union countries such as Italy doesn’t permit new investments in this field and may cause some of them to be referred to the future. New capacities will not be officially announced till the return of the prices, which may take months or even a year. Obviously, the investment in energy in the year 2020 has decreased by nearly 20% in comparison with the same period of time in the year 2019.

However, these findings declare that Italy can turn the crisis of COVID-19 pandemic into an opportunity for expanding the renewable energy sources’ capacity, especially the solar one. Italy’s government should have more encouraging plans and also grant aid to buy renewable electricity. According to the results of this study, due to changes in electricity generation prices and changes in electricity demand during COVID-19, the optimal share of the use of solar energy sources should increase by about 7%.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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