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Impact on energy mix incorporated with nuclear energy by the Coronavirus Disease 2019 (COVID-19) for the post-Corona era in the case of South Korea

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ABSTRACT

It is analyzed for the energy pattern affected by the social matters of the disease trend where the epidemic behavior is significantly important to present the prospect especially for the epidemic of the Coronavirus Disease 2019 (COVID-19). In this work, there are three kinds of data for the modeling where the power transactions, power plant type, and pandemic data are considered by the energy mix of South Korea. The COVID-19 based modeling for Electricity and Nuclear Energy vs. Energy shows that the energy trend decreases until 16.50th week and then it is in the peak point at 32.50th week. Otherwise, the nuclear energy trend decreases until 11.50th week and then it is in the peak point at 27.50th week. The nuclear energy trend increases after 44.25th week. So, the nuclear energy has a better prospect in energy markets. Therefore, the characteristics of an energy source can make an important impact on the market.

1. Introduction

It is analyzed that the energy pattern is affected by the social matters of the disease trend where the epidemic behavior is significantly important to present the prospect. The energy consumption with mixture sources has been reduced following the depression of the national economy. The campaign of social distance for the people has been done voluntarily or legally due to the epidemic of the Coronavirus Disease 2019 (COVID-19) [1–3]. Even the self-isolation should be done for the high fever symptom persons.

Considering the characteristics of the pandemic era, the communication systems are in online networking where the business and educational systems are in the cyber based structures excluding contacting social behaviors such as meeting, grouping, conference, and any kinds of gathering. This is called as ‘untact’ situation [4–9]. Furthermore, the social distance is requested in the public places like dining places, traffic transportations, and public places to reduce or minimize the contagious possibility. Fig. 1 shows the characteristics for the pandemic lives for the post-Corona era. These trends shrink the economic behaviors and eventually decrease the national growth significantly. Although the vaccine prospect and its related R&D could give the people hopes, the milestone of the development is not clear. Therefore, it is reasonable to make the modeling for the energy in the future pandemic.

In the study, for the mathematical modeling of the disease pandemic phenomena, Susceptible - Exposed - Infectious - Recovered (SEIR) model is applied to the energy sectors [10–24]. Especially, the nuclear energy is one of the major portioned energy sources in the nation’s energy industry. Even though the exact estimation could be impossible, the preparation for the next possible pandemic can help us to reduce the damages of the disease control. The modeling is modified by the designed variables of the power production types by the power plants and its related power transaction volume in a nation, South Korea where the nuclear power plants (NPPs) have been operated more than 40 years and it is reasonable to be an example of nuclear energy and pandemic relations. In addition, the COVID-19 outbreak trend is applied for the pandemic data adjustment. If there are more circumstances to be considered in the modeling, it is plausible to add to the model design.

There are some previous studies in the energy status impacted by the pandemic. Vaka et al. worked for the solar energy beyond the COVID-19 pandemic [25]. In addition, Mastropietro et al. worked for the energy consumptions in the pandemic periods [26]. Artificial intelligence (AI) could be investigated in this disease disaster [27]. The energy study has been done in the wide ranges of the power systems and the future planning of the electricity supply could give the modification of technological implications where the pandemic is a very significantly important factor in the R&D of the energy productions [28–33].

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2. Background

Following the pandemic situations, the economic status is in stagnation for a nation where the energy trend is significantly decreasing [34–43]. Fig. 2 shows the COVID-19 impact trend of the power transaction volume in South Korea in which the energy trends of the LNG, nuclear and bituminous coal had been downward from those in December 2019. Usually, this line should rise after one or two months. However, the trend had gone down until May 2020 except bituminous coal. The case of coal could be affected by the national policy to reduce the carbon producing fuel such as the coal fuel. This trend is originated from the pandemic patients. Fig. 3 is the COVID-19 outbreak trend in South Korea. The confirmed patient is in the peak on February 2020 and the death toll is on April 2020. So, the reversal trend of the energy consumption decreasing was not happened and the power transaction volume had decreased until May 2020. Therefore, it is meaningful to expect for the energy transaction volume in the situation of the future pandemic era.

3. Method

There is the modeling of the pandemic in which the SEIR based energy transactions in the mathematical design. The modified SEIR is suitable in the energy sector description, because four variables of SEIR as susceptible, exposed, infectious, and recovered could give the better considerations for the characteristics of energy sources where the base-load power plant and the load-follow power plant are sorted following the electricity production trends in variations of the power level.

3.1. The mathematical model

In the modeling, SEIR model is applied to the South Korean nuclear industry. The basic formulations are described. For the $S$ which is the susceptible one [44],

$$\frac{dS}{dt} = -BSI$$

where $B$ is transmission rate and $I$ is the infectious one. For the dynamical variations of $E$ which is the exposed one,

$$\frac{dE}{dt} = BSI - AE$$

Also, for the dynamical variations of $I$,

$$\frac{dI}{dt} = AE - TI$$

where the $A$ is the reverse form of the latency time and the $T$ is the recovery rate. Finally,

$$\frac{dR}{dt} = TI$$

This can give the future planning of the medical systems. Additionally, the energy demand and supply could be modified.

3.2. The data for modeling

There are three kinds of data to be considered for the modeling where the power transactions, power plant type, and pandemic data in energy mix of South Korea. There are several kinds of energy sources

| Table 1 | List of the power transaction volume in South Korea (GWh). |
|---------|----------------------------------------------------------|
|         | 2019/6 | 2019/8 | 2019/10 | 2019/12 | 2020/2 | 2020/4 | 2020/5 | 2020/6 |
| LNG     | 8997   | 12,083 | 9856    | 16,003  | 13,445 | 9014   | 7251   | 9058   |
| Bituminous Coal | 16,438 | 21,400 | 18,723  | 17,965  | 15,306 | 13,994 | 13,896 | 15,358 |
| Nuclear | 12,934 | 11,597 | 10,071  | 10,514  | 12,087 | 13,049 | 14,555 | 13,409 |
3.3. Power transactions

There is the power transaction volume in South Korea in Table 1 [45] in which the trend had gone down until May 2020 except bituminous coal. Fig. 2 shows the COVID-19 impact trend of the power transaction volume in South Korea.

3.4. Pandemic data

Table 2 shows the list of COVID-19 outbreak trend in South Korea [46,47] in which the confirmed patient is in the peak on February 2020 and the death toll is on April 2020. Fig. 3 shows the COVID-19 outbreak trend in South Korea.

3.5. Power plants type

It is important to analyze the electricity demand reduced by the economic depression in this case of the pandemic situation. There are two kinds of classifications discussed of the modeling. The base-load power plant is to be referring the minimum quantity of the electricity generations [48]. Nuclear, coal, and LNG power plants are classified in this type. Otherwise, the load-follow power plant can be described as following the variations in electricity demand in which nuclear energy is considered in this type [49]. Fig. 4 has the characteristics for the national energy sources where the nuclear energy is included in the base-load and load-follow power plants. Load-follow power plant could be much more effective type, because it is possible to adapt to emergent status in the electricity demands. So, since the nuclear power could be in two power plants type, it is a better energy source.

3.6. Modeling

There are three parts which are important in the modeling as the pandemic patients, the power transaction volume and the power related

Table 2
List of COVID-19 outbreak trend in South Korea.

| Year   | Confirmed | Accu. Conf. | Dead | Accu. Dead |
|--------|-----------|-------------|------|------------|
| 2019/6 | 0         | 0           | 0    | 0          |
| 2019/8 | 0         | 0           | 0    | 0          |
| 2019/10| 0         | 0           | 0    | 0          |
| 2019/12| 0         | 0           | 0    | 0          |
| 2020/2 | 3139      | 979         | 703  | 1331       |
| 2020/4 | 3150      | 10,765      | 11,468 | 12,799    |
| 2020/5 | 17        | 85          | 23   | 12         |
| 2020/6 | 17        | 247         | 270  | 282        |

Fig. 4. Characteristics for the national energy sources.

Fig. 5. Modeling for (a) nuclear energy prospect in COVID-19 pandemic and (b) R.
plant type. Fig. 5 has the modeling for the nuclear energy prospect in COVID-19 pandemic and its related R where the system dynamics (SD) method is used [50–61]. The event networking is connected with Ven-sim code software [62]. Table 3 has the list of modeling variables. In the case of ER, the generated random numbers are obtained of mean with 0.4 between 0.1 and 1.0. The standard deviation is 0.5 + 0.341. In the case of COVID-19, the INTEG means the cumulative function with an initial value of 1. The others are obtained similarly.

4. Results

The COVID-19 based modeling for S, I, E and R is modified from the original modeling where there is a different trend. For example, in the case of S, the graph shows the decreasing from upper-left part, because the disease susceptibility could decrease following some reasons such as the cautious mind. However, in this modeling, it is assumed there is not such mind. Fig. 6 has the COVID-19 based modeling for S, I, E and R, which is based on Tables 2 and 3. That is, Table 2 shows the list of COVID-19 outbreak trend in South Korea, which has constructed each modeling of S, I, E, and R reflecting the infected situations. Then, the variables are decided for the dynamical behaviors of the modeling.

Fig. 7 has the causes loop has Nuclear Energy and R where the event connectivity is seen. In the simulations, Fig. 8 has COVID-19 based modeling results for Electricity and Nuclear Energy vs. Energy where the energy trend decreases until 16.50th week and then it is in the peak point at 32.50th week. Otherwise, the nuclear energy trend decreases until 11.50th week and then it is in the peak point at 27.50th week. Particularly, the nuclear energy trend increases after 44.25th week. So, the nuclear energy has a better prospect in energy markets, although the input variables could make the several results. The energy policy in a nation could be deeply dependable in the non-carbon emission energy source as the energy mix trend. Especially, the nuclear power is one of better energy sources considering the carbon control.

5. Conclusions

It has been for the modeling of the pandemic-based energy trend where the several assumptions are modified incorporated with pandemic infected situation. Therefore, the applications into the real state could be quite different by the specific situations. In this work, the nuclear energy is focused as the mitigating the global warming, because it is a kind of non-carbon emission energy source. So, the eventual pandemic control could be accomplished by reducing or removing the use of carbon emission energy. It is shown of the importance of this study as follows.

- The energy trend is investigated in the COVID-19 pandemic.
- Disease based energy industry is considered for the future estimations.
- Dynamic analysis could give a better assessment in the energy market.

| Table 3 | List of modeling variables. |
|---------|----------------------------|
| Variable | Content |
| S       | INTEG(((SI + I)/S) * 10), Initial Value: 1 |
| I       | INTEG((SI-IE)/(E + I)), Initial Value: 1 |
| E       | INTEG((IE-ER)/(R + E)), Initial Value: 1 |
| R       | INTEG(ER), Initial Value: 1 |
| ER      | RANDOM normal(0.1, 1, 0.4, 0.5 + 0.341, 1000) |
| COVID-19| INTEG (-COVID-19 +Energy)/SEIR + Outbreak Trend, Initial Value: 1 |
| Electricity | RANDOM normal(0.1, 1, 0.4, 0.5 + 0.341, 1000) * Power |
| Nuclear | Electricity/Energy |
| Energy  |                         |

Fig. 6. COVID-19 based modeling (a) S, (b) I, (c) E and (d) R.
Nuclear energy is a prospective source comparing to the others. The AI based analysis can give a better estimation of the energy in-
dustry in a nation in which the networking of the AI property could give
the considerations of the multiple energy sources. By the way, the
advanced AI computing give much better where the data processing
speed could give the real-time estimations that give the fast treatment in
the energy demand. One of the difficulty in pandemic era is to control
the confirmed patient. Whenever the social business opportunity in-
creases, it is easy to be infected by the virus. Hence, the energy demand
is needed to follow the patient numbers, because the government would
reduce or prohibit the social activity due to the newly produced patient
numbers. So, this modeling can be used in the national government to
control the industrial behaviors.

The international cooperation is very important to block the infected
person’s entry. Contagious phenomena are very frequently happened in
the international trades. Therefore, the energy planning should analyze
the international trades in order not to import the virus by the person
or goods. Especially, the shipping of the coal and oil should be non-
f infectious against the virus. Even though the lifetime of disease is not
long as much as it arrives to human as port-worker or customer, the
sanitization is needed to be performed in wide area. In the case of the
COVID-19, the people from the origin of this virus were not blocked in
the early time of the pandemic. Then, the viruses spread in worldwide
regions. These situations were unbreakable and many patient and death
toll increased rapidly. So, the early treatment is very important to con-
tr ol the patient. Then, the energy demand trend could be changeable and
the energy transactions would be formed. As it is seen in this work, the
nuclear energy has the particularly significant trend. Therefore, the
characteristics of an energy source can make an important impact on the
market.

Author contribution

Tae Ho Woo: Methodology, Software, Validation, Formal analysis,
Writing. Kyung Bae Jang, Soo Hyun Ko: Software, Validation. Chang
Hyun Baek: Conceptualization, Project administration, Funding acqui-
sition, Resources.

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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References

[1] BBC, Coronavirus: Covid-19 Outbreak ‘can Be Characterised as a Pandemic’
- WHO, British Broadcasting Corporation (BBC), London, UK, 2020. https://www.
bbc.com/news/av/world-51842838/coronavirus-covid-19-outbreak-can-be-char-
terised-as-a-pandemic-who.
[2] CNN, Coronavirus Pandemic: Updates from Around the World, One CNN Center,
Atlanta, USA, 2020. https://edition.cnn.com/world/live-news/coronavirus-pand-
emic-05-22-20-intl/index.html.
[3] UNDP, COVID-19 Pandemic Humanity Needs Leadership and Solidarity to Defeat
the Coronavirus, Headquarters United Nations Development Programme, One
United Nations Plaza, New York, USA, 2020. https://www.undp.org/content/
undp/en/home/coronavirus.html.
[4] L. Altinay, M. Kozak, Revisiting destination competitiveness through chaos theory:
the butterfly competitiveness model, J. Hospit. Tourism Manag. 49 (2021)
331–340.
[5] Y. Jadil, M. Ouzir, Exploring the predictors of health-protective behavior during
the COVID-19 pandemic: a multi-country comparison, Environ. Res. 199 (2021)
111376.
[6] J. Kang, Introduction to the special issue: “Nursing education and research in the
remote era”, Asian Nurs. Res. (In Press).
[7] S.M. Lee, D.H. Lee, Opportunities and challenges for contactless healthcare services
in the post-COVID-19 Era, Technol. Forecast. Soc. Change 167 (2021) 120712.
[8] S. Roth, The Great Reset. Restratification for lives, livelihoods, and the planet,
Tech. For. Soc. Chan. 166 (2021) 120636.
[9] Y. Yang, C.X. Zhang, J.M. Rickly, A review of early COVID-19 research in tourism:
launching the Annals of Tourism Research’s Curated Collection on coronavirus and
tourism, Ann. Tourism Res. 91 (2021) 103313.
[10] M. Partohaghighi, A. Akgil, Modelling and simulations of the SEIR and blood
cogulation systems using atangana-baleanu-caputo derivative, chaos, solit, Fract.
150 (2021) 111135.
