# EFFECTIVE METHOD OF LEARNING BASIC ENERGY MIX USING ANALOG GAMES

Tomomi Kaneko* [a] and Noritaka Yusa[b]

[a] NIT Tomakomai College, Tomakomai, Japan
[b] Tohoku University, Sendai, Japan

Tomomi Kaneko * (t_kaneko@tomakomai-ct.ac.jp)

**Extreme weather events have been increasing in recent years because of global warming. In Japan, record-breaking rainfall, heavy snowfall, and prolonged periods of extreme heat are becoming more common. In Tomakomai, summers are getting hotter; winters are not as cold as they were. To mitigate global warming (JCCCA Homepage), it is crucially important to reduce greenhouse gas emissions, particularly those from power generation, which is an important contributor. Thermal power generation by coal, oil, and natural gas allows easily adjustable output fluctuations, but it emits greenhouse gases. Nuclear power generation emits no carbon dioxide, but radioactive waste persists as a challenging difficulty. Renewable energy sources such as solar, wind, and hydropower generation depend on natural conditions. Power generation modes have their respective benefits and shortcomings. At NIT Tomakomai College, lectures address characteristics and examples of various power generation modes. However, determining the optimal combination of these power generation modes is challenging. Teachers often emphasize the importance of adapting the energy mix to circumstances, but explaining the process of finding the best mix is not straightforward. To address this challenge, an analog board game was introduced into lectures to help students understand energy mix difficulties experientially. In the game, students play the role of a person in charge of introducing and developing energy infrastructure in their country, considering greenhouse gas emissions. Fundamentally, the game winner or loser is decided on the level of development which is achieved. Throughout the game, students learn concepts of combining seven modes of power generation experimentally. The game is well accepted by the students. By playing repeatedly, they experience various energy mix patterns and more deeply understand how different mixes function. The analog board game introduced into lectures at NIT Tomakomai College has proven to be an effective educational tool. This innovative approach has enhanced student understanding of energy mix complexities and the importance of reducing greenhouse gas emissions.**

***Keywords:*** *Analog game, Energy mix, Greenhouse gas emissions, Power mix, Practical lectures*

## Introduction

At 3:07 AM on September 6, 2018, the author's surroundings were struck suddenly by a large tremor: the Hokkaido Eastern Iburi Earthquake. The author immediately checked the earthquake information available on the TV, but the electricity supply soon stopped: TV transmissions ceased. Information was obtained via smartphone, revealing that the entire Hokkaido area had experienced black out. The author, who had a business trip that day, assumed that power would be restored soon. However, the power was not restored. The airport remained closed. Consequently, the business trip had to be cancelled. Electricity was not restored for more than an entire day, causing considerable inconvenience to daily life for all residents. The earthquake, which occurred in early morning, led to the shutdown of the Tomatoh Atsuma Thermal Power Station near the epicenter, which provided approximately half of Hokkaido's electricity demand at that time. Consequently, the supplied electricity was insufficient to meet overall demand, resulting in a large-scale blackout throughout Hokkaido: the first such experience in that region. This experience highlighted the risk of relying on a single power source and underscored the importance of diversifying electric energy generation sources, constituting the energy mix. When institutions of engineering education teach aspects of the energy mix, they naturally emphasize the technical characteristics of each source. The energy mix is often characterized as the optimal combination of the respective sources. However, understanding this optimal combination is challenging. To address this point, the authors incorporated an analog board game into lectures to help students understand the energy mix experientially. In the game, students take on the role of individuals responsible for introducing and developing energy infrastructure in their country, particularly considering greenhouse gas (GHG) emissions. By playing the game repeatedly, students consider and implement various energy mix patterns, gaining deeper understanding of how different mixes work. This experiential learning approach proved effective for enhancing students' comprehension of the subject matter.

## Materials and Methods or Pedagogy

This section provides an overview of the game the authors developed. The fundamental aspects of the games are the same as those reported in earlier studies (Yusa and Hamada, 2021; Yusa and Hamada, 2023; Hamada, Nakayama and Yusa, 2024), but several updates were made to enhance the game playability. The information in this article is insufficient to reproduce the game. The authors are pleased to offer, upon request, full information necessary to play the latest version of the game.

Figure 1 shows how the game is played. The game has an analog-type board game for 3–5 persons (or groups, hereinafter "player"). Each player becomes the representative of a country and supplies power to the country by arranging power sources and resources. If the power requirement is satisfied, then the country will develop; otherwise, the development will stagnate. The winner is the player who gained the highest score based on the development and owned assets at the end of the game. The game is designed to foster understanding of energy and related issues from a Japanese viewpoint.

Figure 1 Overview of the game.

The power generation facilities of seven types have different characteristics: coal-, oil-, and gas-fired plants; nuclear power; hydropower; solar power; and wind power. The first four respectively require resource inputs to generate power: coal, oil, gas, and uranium. The others can generate power without resource inputs. The three fossil-fired power generation facilities generate GHG proportionally to the generated power: the others do not. The four resources, which are represented using dice, have different characteristics. Coal and uranium are abundant, whereas oil and gas have more limited supplies. The price fluctuations of coal, oil, and gas are, respectively, small, large, and medium, whereas the uranium price remains unchanged. The prices of power generation facilities and resources were determined based on actual prices in Japan during recent decades. In the game, cards and dice respectively represent power generation facilities and resources. Initially, each player has four cards as shown in Figure 2. All of them are classified as "level 1," which means that their outputs are relatively small. The coal-, oil-, and gas-fired power generation facility cards indicate that each can generate 2 TWh per resource, with a maximum of two resources accepted. In contrast, the hydropower facility can generate 0.5 TWh without consuming any resources.

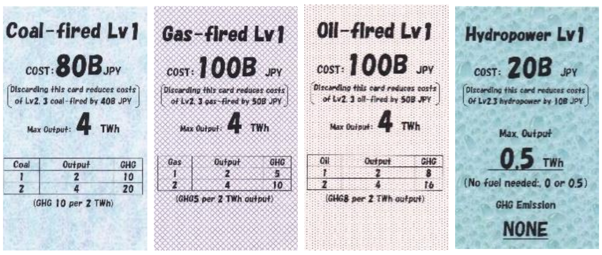


Figure 2 Cards owned at the beginning of the game.

If players want to increase power generation capacity, then they can expand or upgrade their power generation facilities. For example, if they want to increase coal power capacity, then they can expand or upgrade facilities as shown in Figure 3. First, the player had a level 1 coal power facility. A player seeking to expand a level 2 facility must pay 160 billion yen to obtain one more facility unit. If a player pays 120 billion yen, the player can replace the level 1 facility with a level 2 facility that emits less GHG per power generation.

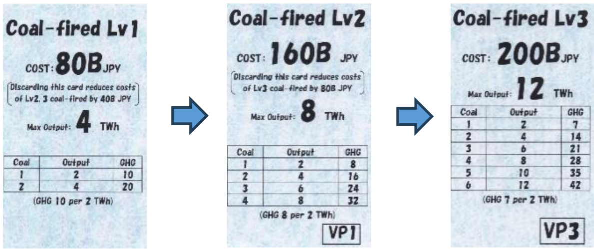


Figure 3 Example of facility upgrade.

Figure 4 shows that this game has four power generation modes without carbon dioxide emissions. The output of a nuclear power facility is not controllable unlike those of the fossil-fired power facilities. Nuclear power facilities generate a constant amount of power using a fixed amount of fuel. The outputs of solar and wind power facilities fluctuate randomly, as determined by dice rolls.

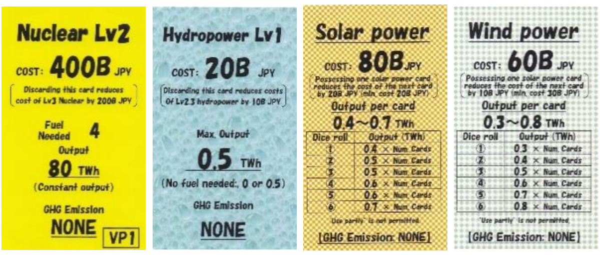


Figure 4 Power generation without carbon dioxide emissions.

One round of a game has eight phases. An overview of what players do in the phases is presented below.

- Phase 1: Revenue and Investment

  Each player earns revenues according to the country development. Then, players auction investment cards that have positive effects, such as the increase in the GHG limit and mitigation of the possibility of nuclear accidents.

- Phase 2: Purchasing power generation facilities
  One by one, players purchase power generation facilities on the field until all players have bought the cards they want to purchase.
- Phase 3: Event
  Event cards are drawn from the pile to generate events. Various events are prepared, such as changes in specific resource prices.
- Phase 4: Purchasing resources
  One by one, players purchase resources in the field or sell possessed resources to the market (field).
- Phase 5: Power generation
  Players use the power generation facility cards and the resources they own to generate electricity to meet power demand and GHG emission limits. Insufficient power supply incurs a strong penalty.
- Phase 6: GHG reduction
  Players vote for one of three options to reduce their GHG limits. Negotiations are permitted, as are acquisitions and even betrayals.
- Phase 7: Resource market update
  The prices and numbers of resources in the fields are updated. Prices typically increase every round.
- Phase 8: Development
  Players who satisfied the requirements increase their development levels from +1 to +3 from the current level. A higher level leads not only to larger revenue but also to greater power demand.

Players play three rounds on one game. An A5-size rule card summarizing the procedure described above is given to each player, as portrayed in Figure 5.

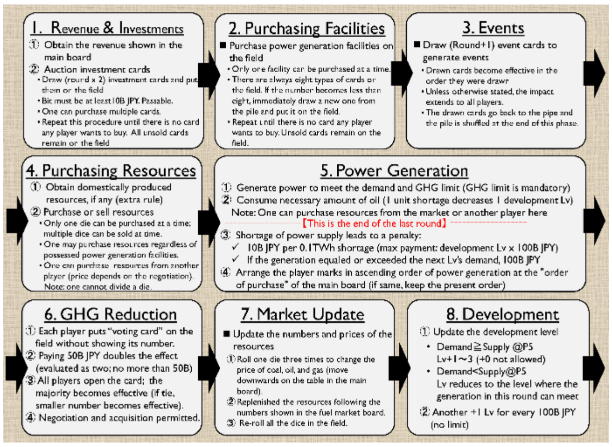


Figure 5 Rule card.

The basic game method is described above, but real-world countries have their unique characteristics. Therefore, the authors defined the following features as prerequisites for the energy mix. Students selected from among them to assign each country its own unique characteristics. Hereinafter, such an operation is designated as the "country-specific version." Card features are the following.

A. Oil Field Holdings
   Obtain 2 oil dice at the beginning of every round. Minimum price 150 billion yen.
B. Large Oil Field Holdings
   Obtain 2 oil and 2 gas dice at the beginning of every round. Minimum price 300 billion yen.
C. Large Coal Field Holdings
   First 2 coal dice obtained in each round. Minimum price 100 billion yen.
D. Gas Field Holdings
   Obtain 2 gas dice at the beginning of every round. Minimum price: 150 billion yen.
E. Electricity imports available (2 pieces)
   May purchase up to 5 billion kWh of lack of electricity per piece. Minimum price 50 billion yen.
F. GHG limit not ratified.
   GHG limit always remains at 800 and ignores all GHG limit increase/decrease events. Minimum price 10 billion yen.
G. Large flat areas
   Two rolls of the dice when determining the amounts of wind and solar power generation. Minimum price 50 billion yen.

## Results and Discussion

The authors administered the lecture of "Advanced Environmental Engineering for Cold Region" for advanced engineering course first grade students majoring in mechanical engineering. The lecture objectives are the following.

(1) Explain the relation between economic development and energy consumption.
(2) Explain the basic mechanisms of greenhouse gases and global warming.
(3) Explain devices using renewable energy.

During the third quarter of the first week of the term, the authors explained the course guidance, the status of energy conservation, and new energy usage in Hokkaido. From the second week, one of the following power sources was picked up for each lecture. Each student researched their technical characteristics and installation and gave presentations to each other.

- solar power generation
- wind power generation
- biomass power generation.
- geothermal power generation
- small and medium-scale hydropower generation
- snow and ice cryogenic power generation.
- nuclear power generation.
- thermal power generation

During the fourth quarter, the authors conducted the energy mix game with students as three intensive lectures. These lectures covered the game background and instructions on how to proceed. Students played one basic game and one country-specific version as Game 1. For the subsequent three lectures, students played the game of country-specific version as Game 2, Game 3, and Game 4. At this time, the authors asked the students to adopt different country-specific features each time. Table 1 presents the students' selections.

Table 1 Student selections of country-specific cards

| | Game 1 | Game 2 | Game 3 | Game 4 |
|---|---|---|---|---|
| Student A | G | B, F | E | No Use |
| Student B | C | A | A, D | A, D, F |
| Student C | B | D | F | E |
| Student D | E | E | E, G | No Use |
| Student E | E | B | C, F, G | G |

A. Oil Field Holdings
B. Large Oil Field Holding
C. Large Coal Field Holdings
D. Gas Field Holdings
E. Electricity imports available (2 pieces)
F. GHG limit not ratified
G. Large flat areas

After the lecture, the authors conducted a periodic exam and a questionnaire.

Periodic examination – Question 1

In Japan, to what ratio do you think the seven types of power generation (coal-fired, oil-fired, gas-fired, hydroelectric, solar, wind, and nuclear) should be used? Present the percentage of each type, taking the total amount as 100%, and provide reasons for your response within 270–300 words.

Answer – Student C

Because thermal power generation is stable and its output can be adjusted, it was considered optimal to cover about half of the power needs using thermal power generation. The percentage of nuclear power generation would vary depending on the introduction of small nuclear reactors, which have a lower risk of accidents. Therefore, this mix was deemed appropriate. Wind and solar power are unstable in terms of output, so their percentage was estimated as low. Regarding the breakdown of thermal power generation, the emphasis was on gas-fired power generation, which emits low amounts of carbon dioxide. The share of oil was set as about 5%, in light of increasing uncertainty in the Middle East. Coal-fired power was also regarded as at a similar level because of its low cost. The share of thermal power was set as about half to accommodate hydrogen-fired power generation technology, which might be realized in the future. The result of Student C is shown in Figure 6.

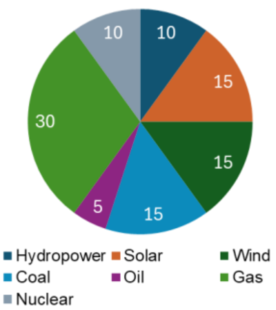


Figure 6 Result of Student C.

Answer – Student E

In Japan, there is currently a need to move away from dependence on fossil fuels. One reason for Japan's fossil fuel dependence is the sharp decline in nuclear power plant use following the Fukushima Daiichi nuclear power plant accident, which has been replaced by thermal power generation. Going forward, Japan plans to reduce coal-fired, oil-fired, and gas-fired thermal power plants, which currently account for about 80% of its power generation, by nearly half, and to promote the reintroduction of nuclear power generation. In addition, Japan aims to introduce much wider use of renewable energy sources, with solar, wind, and hydroelectric power each accounting for 15% of power generation. Nuclear power and renewable energy will become the mainstays of power generation. The proportions of power generation systems using fossil fuels are set as 5% coal-fired, 6% oil-fired, and 9% gas-fired, concerning GHG emissions in the energy game. The result of Student E is shown in Figure 7.

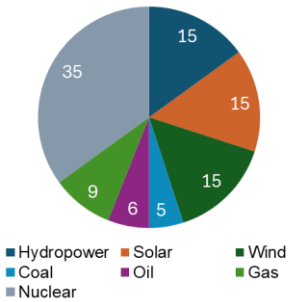


Figure 7 Result of Student E.

The ideal Japanese power source composition estimated by the students, based on their proposals, is presented as Table 2.

Table 2 Analyze students' suggestions

| | Average | Maximum | Minimum | Standard deviation |
|---|---|---|---|---|
| Hydropower | 13.7% | 30.0% | 5.3% | 8.8% |
| Solar | 11.7% | 15.0% | 8.0% | 2.8% |
| Wind | 11.7% | 15.0% | 8.0% | 2.8% |
| Coal | 10.1% | 20.0% | 5.0% | 6.3% |
| Oil | 6.7% | 10.0% | 5.0% | 1.8% |
| Gas | 15.9% | 30.0% | 9.0% | 7.4% |
| Nuclear | 30.3% | 52.6% | 10.0% | 14.5% |

| | |
|---|---|
| Renewable energy * | 37.1% |
| Thermal power ** | 32.7% |
| Nuclear power | 30.3% |

* Renewable energy: hydropower, solar and wind
** Thermal power: coal, oil and gas

However, according to the Seventh Strategic Energy Plan announced by the Ministry of Economy, Trade and Industry in February 2025, the power source composition in 2040 is projected as shown in Table 3.

Table 3 Power source composition in 2040

| | |
|---|---|
| Renewable energy * | approx. 40% – 50% |
| Thermal power ** | approx. 30% – 40% |
| Nuclear power | approx. 20% |

* Renewable energy: hydropower, solar and wind
** Thermal power: coal, oil and gas

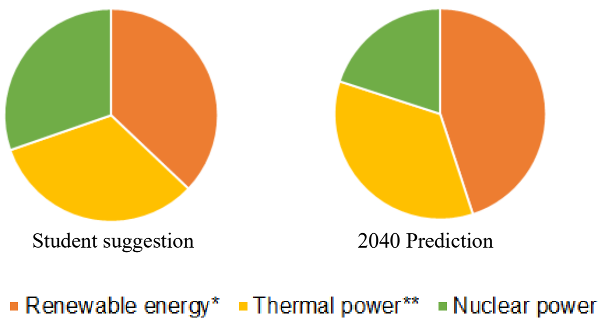


Figure 8 Average result of student suggestions.

Student suggestions and 2040 predictions are presented for comparison in Figure 8. Results were generally similar, but the student proposals included slightly more nuclear and less renewable energy. This comparison suggests that students were able to learn power source composition concepts experientially through game play.

Periodic examination – Question 2

For a country to satisfy more than half of its electricity demands with wind and solar power, what conditions would be necessary for the country's ratio of power sources? Illustrate the percentages and describe the conditions in 270–300 words.

Answer – Student B

Wind and solar power generation, which do not emit greenhouse gases, are attracting attention as clean energy sources. However, power generation capacity is dependent on weather conditions. Therefore, other types of power generation must generate sufficient power to compensate for fluctuations in power generation from wind and solar sources. We propose combining nuclear power, which can generate electricity on a large-scale, with hydropower, which is clean and efficient, and gas-fired thermal power, which emits less GHG amounts and generates appreciable amounts of electricity. To meet more than half of electricity demand using wind and solar power, power generation systems must be installed in certain locations to generate wind and solar energy with very low environmental impacts. Furthermore, electricity consumers must adopt more energy-efficient home devices and other systems to reduce power consumption. The result of Student B is shown in Figure 9.

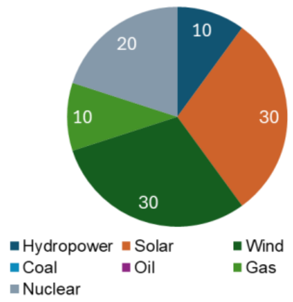


Figure 9 Result of Student B.

Answer – Student D

We believe that countries with a high percentage of renewable energy should have at least 30% of their power generation provided by thermal power using fossil fuels such as natural gas, oil, and coal. The reasons for this are multifaceted. First, renewable energy sources are unstable because the amounts of power generated fluctuate greatly depending on the weather. Secondly, the cost of generating power from renewable energy sources is high. Thirdly, the construction of large-scale renewable energy power plants requires large tracts of land, which can have an impact on the environment. By securing at least 30% of thermal power generation, which can provide stable power generation, power can be generated mainly from renewable energy sources with greater reliability. This approach also helps prevent unnecessary deforestation and other environmental effects associated with large-scale renewable energy projects. The result of Student D is shown in Figure 10.

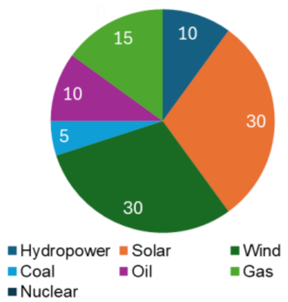


Figure 10 Result of Student D.

The results confirmed that the students are aware of practical issues and some idealistic notions of renewable energy introduction.

A questionnaire was administered. Responses were received from three respondents as shown below.

Questionnaire – Q1

How did you feel about this game?

- ✓ Initially, I did not have a good understanding of the characteristics of each type of power generation; there were many challenges. However, as the number of sessions increased, I found it very interesting to learn about the energy mix which leverages the strengths of each power generation mode.
- ✓ I enjoyed learning about the mechanisms of power generation, greenhouse gas (GHG) emissions, and the

benefits and shortcomings of each power generation method.

- ✓ Players can reduce power generation facilities to a minimum by lowering the initial development level to avoid going into debt. Alternatively, they can borrow large amounts of money early to buy country-specific cards and investment cards, aiming at considerable profits and subsequent repayment. Another strategy involves using renewable energy or nuclear power to reduce greenhouse gas emissions, thereby adversely affecting the surrounding environment. The final score can change considerably depending on how the game is managed. Strategies such as using renewable energy or nuclear power to reduce greenhouse gas emissions can make the game more challenging for other players. The winner is chosen according to the final score, which varies greatly based on the chosen strategies and game management.

Questionnaire – Q3
Did repetition of the game deepen your understanding of the energy mix?

The results of Q3 are summarized in Table 4.

Table 4 Results of Q3

| | |
|---|---|
| Did not deepen my understanding of the energy mix at all | 0 |
| Did not have a good understanding of the energy mix | 0 |
| Understanding of the energy mix was neither | 0 |
| My understanding of the energy mix has deepened | 1 |
| My understanding of the energy mix is very good | 2 |

Students' answers to "Please tell us why you gave the response shown above" are shown below:

- ✓ In the first game, the final development level stopped at 5. However, as the number of games increased, our understanding of the characteristics of thermal power, nuclear power, and renewable power improved. We succeeded in combining them effectively. In the last game, the final development level reached 8 while meeting GHG restrictions.
- ✓ The reason for this improvement is that, by playing the game with a broad perspective and with consideration of factors such as GHG emissions, resource prices, power generation equipment prices, and country characteristics, the final score increased along with the number of times the game was played.
- ✓ I am now able to consider characteristics of thermal, hydro, nuclear, wind, and solar power and ascertain which to use and how much to use to meet my power generation requirements and greenhouse gas emission limits. This improvement is attributable to our enhanced ability to evaluate the characteristics of thermal, hydro, nuclear, wind, and solar power generation and to make informed decisions about their usage and proportions.

The students enjoyed participating in game-based education and deepening their understanding through repeated game play.

## Conclusions

In lectures for mechanical engineering students, the authors were able to address energy issues, which tend to be biased toward technical elements, by extending their exposure to the energy mix through the use of games. As a result, the students were able to think independently about the energy mix, often suggesting, "Just make it optimal." Consequently, they were able to propose a mix that closely resembled Japan's future power supply mix. However, the players were few (5 students), constituting a small sample. The authors will strive to increase the sample size by continuing to offer these lectures in future courses for additional consideration and validation.

## Acknowledgments

The authors extend their deepest gratitude to the foundation for the Fusion of Science and Technology (FOST) for financial support of our research.

## References

The Japan Center for Climate Change Actions (JCCCA), https://www.jccca.org/lp/english

Hamada, R., Nakayama, S. & Yusa, N. (2024). Integrating the country's energy situation and inter-national greenhouse gas reduction negotiations into a board game for understanding the best power mix. 2024 Autumn Meeting of the Japan Association of Simulation and Gaming. 2024/11/23-24.

Ministry of Economy, Trade and Industry (2025). the Seventh Strategic Energy Plan, https://www.meti.go.jp/english/press/2025/0218_001.html

Yusa, N. & Hamada, R. (2021). Development of a board game for studying energy mix. *Journal of Energy and Environmental Education*, 15, 21-28.

Yusa, N. & Hamada, R. (2023). Board game design to understand the national power mix. *Education Sciences*, 13, 793.