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Board Game Design to Understand the National Power Mix

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Abstract: This study reports a board game design that would be an effective tool for teaching and learning the best mix of national power sources in a class concerning energy and sustainability in higher education courses. A board game was developed to understand the characteristics of power sources from a Japanese viewpoint based on an earlier study of the authors. The purpose of the game is to satisfy electricity demands by choosing power sources and procuring the resources necessary for power generation to help develop a country. A total of 50 undergraduate and graduate students were asked to assess the game. The results of the questionnaire-based survey conducted after the game confirmed the students' evaluation that the game was highly enjoyable and could serve as an effective tool for energy and environmental education in high schools or universities. In addition, the average of "the ratio of the power sources proper to win the game" given by the students was similar to Japanese power mix before the Fukushima disaster, although the game significantly simplified, and even excluded, various factors affecting the national policy of power sources.

Keywords: best mix of power sources; public acceptance; energy policy; electricity supply; simulation and gaming; game-based learning

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1. Introduction

Access to affordable, reliable, sustainable, and modern energy is one of the most important issues in present society and is designated as Sustainable Developed Goal 7 (SDG7) by the United Nations. Meanwhile, a national policy to ensure energy and electricity is a difficult issue for each country because there are a large number of factors, as well as their uncertainties, to be taken into consideration. Whereas the resources produced domestically comprise one of the essential factors, most countries need to import energy resources from other countries. Thus, they have to consider not only the availability of resources in the international market but also other complications, such as geographic and political matters. In addition, from a domestic perspective, a national government cannot ignore the public acceptance of power sources. In particular, it is difficult for a country to promote power sources with little public acceptance even though they are cost-effective and advantageous for energy security.

Thus far, many studies have discussed the factors affecting public attitudes toward energy and electricity [1]. However, it is difficult to discuss quantitatively how to improve public acceptance of a specific power source. Consequently, most of the activities aimed at enhancing public acceptance of power sources intend to offer knowledge on the characteristics of various power sources. Each power source has advantages and disadvantages. Focusing only on the advantages would lead to irrational dependence on a single source, while focusing only on the disadvantages would lead to the refusal of any power source. What is essential is the discussion on the best mix of power sources. However, discussing the extent to which a country should use each power source requires knowledge on the various issues mentioned above. For example, surveys by Japan Atomic Industrial Forum have reported that about half of university students in Japan insisted on using solar and wind powers as much as possible, and the majority preferred not using or refraining from using nuclear power as a national power source 30 years later [2]. Obviously, these answers lack such a viewpoint regarding "how much of the whole" we should use from each power source. In contrast, it is challenging to offer knowledge necessary to quantitatively discuss the proper ratio of each power source to people, especially those who are not so very interested in the details of energy and power, so that they understand and consider the best mix of power sources from a national viewpoint.

Game-based learning is one of the possible ways to teach the essence of something complicated [3–6]. Proper gaming enables players to virtually experience what they should learn, which not only offers knowledge to them but also motivates them to study actively. Whereas gamification has been developed mainly in the business sector, recent studies have confirmed its effectiveness in teaching science and technology (see, for example, [7–15]). Game-based learning methods are roughly divided into two categories: digital and non-digital ones. Whereas both have pros and cons, non-digital ones requiring multiple persons to play together have the capability of involving those who are not so interested in the topic the teachers intend to teach [16,17]. There are non-digital games designed to teach energy and power in a class, such as the ones listed in [18,19]. However, to the best of the authors' knowledge, they are for elementary or secondary education levels and thus do not attempt to deal with the complexity associated with the choice of power sources. Several famous non-digital games that request players to find the best solution under complex and uncertain situations are available on the market, such as Power Grid (by Friedemann Friese) and Power Failure (by Tao-Tao Chen et al.). However, playing them does not necessarily lead to a better understanding of power and the related issues; they could be even misleading because they were designed to be enjoyable as a commercial product. This motivated the authors of the current study to develop a board game to teach the characteristics of power sources. Pilot studies by the authors have confirmed that a board game could be an effective tool to teach the characteristics of power sources [20,21]. The results of pre- and post-tests in the pilot study revealed that playing the game led to students' better understanding of the general and qualitative characteristics of power sources. However, the game used in the pilot studies focused on the economic aspects of power sources and did not consider several important matters, including the possibility of nuclear accidents, that affect the public acceptance. The evaluations were performed by those who played the game only once. Thus, their assessments may have been greatly affected by the randomness implemented in the game. In addition, debriefing was not performed, which indicates that further studies, including improving the game, are indispensable for further discussion of the possibility of using a board game to teach and learn not only national power policy but also the characteristics of power sources.

Based on the above background, the current article reports the authors' attempts to evaluate the possibility of using a non-digital board game to teach and study the important factors affecting the best mix of national power sources at a higher education level. Specifically, in this study, the authors enhanced the board game they developed to represent the advantages and disadvantages of each power source more reasonably while significantly improving its playability. The updated version of the board game was evaluated by 50 graduate and undergraduate students. The results of their evaluations revealed that the board game was highly enjoyable and effective in helping them understand the characteristics of the seven power sources featured in the game. Furthermore, the ratio of the power sources the students considered "appropriate to win the game" after playing the game was similar to that of Japan before the Fukushima accident.

2. Materials and Methods

2.1. Overview of the Game

Figure 1 presents an overview of the developed board game. The game is an analog-type board game that does not use computers and instead uses cards, dice, pens, and so on. The game is played by four players. In the game, each player serves as the chief executive officer of an electric power company entrusted with the power supply of a certain country. Players need to choose power sources and procure resources to supply the stable electricity necessary for developing the country. If the electricity requirement is satisfied, the country will develop, and the player will receive great rewards; otherwise, the development will stagnate. Although the required electricity will increase with the development of the country, the amounts of available resources and that of greenhouse gas (GHG) emissions permitted are limited. Events that change the situation, such as the availability of power generation facilities or resources, are randomly generated. Thus, it is necessary to consider the characteristics of each power source and adopt appropriate strategies based on the resource market, other players' intentions, possible events, and so on. The winner is the player who garners the highest score based on the development and owned assets at the end of the game.

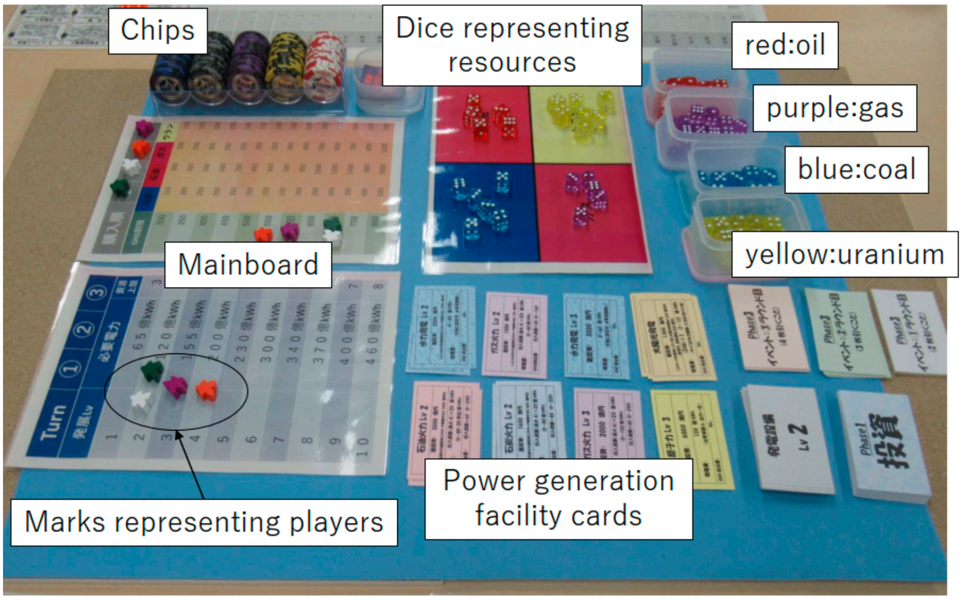

Figure 1. Overview of the game.

The game considers seven kinds of power generation facilities with different characteristics: coal-, oil-, and gas-fired powers; nuclear power; hydropower; and solar and wind powers. The first four require resources—coal, oil, gas, and uranium, respectively—for generating power; the others can generate power without resources. The three fossil-fired power generation facilities generate GHG proportional to the generated power, whereas the others do not. Tables 1 and 2 summarize the characteristics of the facilities and the resources in the game, respectively. The game was designed to model the Japanese situation on energy and electricity. Thus, it postulates that the countries have no natural energy resources and cannot import or export electricity from abroad. Furthermore, the numerical values in the game, such as the prices of power generation facilities, were determined with reference to the Japanese context. The increase in the required electricity was also determined based on the increase in electric power consumption in Japan in the last several decades, specifically 1/25 of those from 1965 to 2005.

Table 1. Characteristics of the seven power sources featured in the game.

	Resource Needed	GHG Emission	Characteristics
Coal-fired	Coal	Large	Output is proportional to resource input.
Oil-fired	Oil	Middle	Output is proportional to resource input.
Gas-fired	Gas	Small	Output is proportional to resource input.
Nuclear	Uranium	None	Output is constant. There is a small possibility of "nuclear accidents" that impose serious negative consequences on players with nuclear power plants; the possibility can be reduced by an investment.
Hydropower	None	None	Output is variable (controllable), but the maximum capacity is sometimes affected by the waterfall.
Solar	None	None	Output fluctuates (uncontrollable). The cost of construction is reduced with the number of solar power facilities already possessed by a player.
Wind	None	None	Output largely fluctuates (uncontrollable). The cost of construction is reduced with the number of wind power facilities already possessed by a player.

Table 2. Characteristics of the four power resources featured in the game.

	Price Fluctuation	Supply
Coal	Small	Plentiful
Oil	Large, affected by events	Constant but affected by events
Gas	Small, affected by events	Constant but affected by events
Uranium	Very small	Plentiful

At the beginning of the game, the amount of electricity required is not large, and it is highly probable that using coal-fired power is the most effective way because of its abundant and cheap resources. In contrast, players will soon face the necessity of using multiple power sources to mitigate the possibility of electricity shortfall to understand that the best mix of power source depends on the development of a country. There should be no strategy that assures a player of winning the game, as there are many uncertainties (mainly due to the roll of a dice) in the game. However, the game is designed such that improper decisions that do not consider the characteristics of power sources lead to poor scores. More details on how to play the game are presented in Appendix A.

The fundamental part of the game is the same as the original version reported in an earlier study by the authors [20]. However, several major updates were performed to highlight GHG-emission-related issues and the characteristics of power sources, including the possibility of nuclear accidents. In addition, many minor updates were carried out to enhance the playability of the game, which not only made the game more enjoyable but also enabled players to concentrate on essential aspects. These updates also shortened the time necessary for playing the game. While it took almost two hours to finish one game in the original version, the present one requires approximately one hour if at least one of the players has played the game and understands the rules. This makes it easier to use this game in lectures. Whereas the game is basically for four players (or teams), it also works well with three or five players (or teams), with slight modifications in the number of items used in the game.

It should be emphasized that the game was designed as a teaching tool in a class of higher education concerning energy and sustainability to motivate participants to study energy and electricity in general rather than to elucidate the details about these topics. Thus, this game does not postulate that players have some knowledge about and even an interest in energy and electricity, whereas it requires fundamental knowledge about science and technology that students should learn in secondary education. In addition, unlike commercial board games, it does not assume that this game is played many times. Because making the game more realistic, which usually leads to more complexity, does not always enhance but frequently reduces the interest of players, some aspects are quite simplified or even ignored so that players can study essential concepts about the best mix of power sources while having fun (and concentrating) within a limited amount of time.

2.2. Respondents and Procedure

Because the game was designed for a class in a higher education, this study gathered a total of 50 undergraduate and graduate students (hereafter denoted as "respondents") for evaluating the game. Their profiles are summarized in Table 3. Those whose major is education belonged to Miyagi University of Education, while the others studied at Tohoku University. Five of the respondents had played an earlier version of the game in an earlier study conducted by the authors [20].

Table 3. Profiles of the respondents (N = 50).

Item	Content	Frequency (Ratio)	
Gender	Female	31	(62%)
	Male	14	(28%)
	Unknown	5	(10%)
Grade	Bachelor	33	(66%)
	Master	11	(22%)
	Doctoral	1	(2%)
	Unknown	5	(10%)
Major	Agriculture	1	(2%)
	Education	13	(26%)
	Engineering	26	(52%)
	Nursing	3	(6%)
	Science	2	(4%)
	Unknown	5	(10%)
Age	18–19	8	(16%)
	20–21	21	(42%)
	22–23	14	(28%)
	27	1	(2%)
	29	1	(2%)
	Unknown	5	(10%)

It is highly likely that the respondents' evaluations would be biased if they played the game with the authors. Hence, the authors played the game with five other undergraduate or graduate students belonging to the first author's research group (hereafter denoted as "moderators") a few times in advance, and the moderators played the game with the respondents so that they could subsequently evaluate the game using a questionnaire. The respondents from Tohoku University were gathered by the moderators and the first author, while those from Miyagi University of Education were recruited from open calls at lectures. All the respondents remained anonymous to the authors until they finished evaluating the game. More specific details of the procedure are given below.

1. First, a moderator explained the overview and game mechanics to the respondents;
2. The moderator and the respondents played only the first round of the game so that the respondents could understand the mechanics of the game. This part was omitted if the moderator found it unnecessary because, for example, all the respondents were familiar with board games, and the explanation above enabled the respondents to sufficiently understand how the game was played;
3. The moderator and the respondents played the game twice, from the beginning until the end, to mitigate the effect of the randomness of the game on the respondents' thoughts on the game. They had a break of up to 30 min between the two games;

4. Copies of a six-page document explaining the background of this game and related issues were distributed to the respondents. The respondents were requested to carefully read the contents of the document as the debriefing of the game. The contents of the document included the relationships between energy, electricity, and the gross domestic product per capita; how the prices of the power generation facilities and the resources were decided upon; and why players could increase the GHG limit if they chose the low development level at the beginning;
5. The four-page questionnaire form, whose contents are given in the next subsection, was distributed to the respondents. The respondents were requested to answer the questions. The beginning of the questionnaire stated the following: the results of this survey will be published at an academic meeting or in an academic journal; the answers will be treated as anonymous; it is not necessary to answer all questions; and the answers will not lead to any negative effect.

It took five to six hours to complete the process described above. As all the moderators and respondents were Japanese, the games were played using the language as presented in Figure 1. All the explanations as well as the conversations during the game were also in Japanese.

The respondents were grouped into 18 groups based on their personal relationships so that they could play the game with their friend(s). Each group played the game individually from the middle of April to the end of June 2022, December 2022, and June 2023. Three of the eighteen groups consisted of two respondents and two moderators, while the others consisted of three respondents and one moderator. One of the groups with one moderator included one respondent who had already played the game and answered the questions in another group. The answer from that respondent was gathered only once.

2.3. Questionnaire Items

Table 4 summarizes the items contained in the questionnaire. The first seven items, Q1–9, were scored using a seven-point Likert scale (1 = strongly disagree, 4 = neither agree nor disagree, 7 = strongly agree). They were basically the same as the ones used in the authors' earlier study to evaluate the first version of the game [20], except that the earlier study asked about effectiveness in elementary or junior high schools as Q7. The rest, i.e., Q8 and Q9, were presented as open-ended questions. The questionnaire contained a few additional open-ended questions. Respondents' answers to these additional questions are not reported in detail here, as they were about the development of the game in the future, including respondents' general impressions of the game and the debriefing material, whereas they were used to analyze and discuss the answers to Q1–9. The questionnaire was four pages on A4 paper because Q8 and the additional open-ended questions requested the respondents to offer a sufficient amount of information necessary to analyze the answers. The questionnaire was in Japanese.

Table 4. Questionnaire items.

ID	Content
Q1	The game is enjoyable.
Q2	The game is well balanced.
Q3	The rules of the game are easy to understand.
Q4	Playing the game is a good opportunity to think about energy.
Q5	This game leads to an understanding of the characteristics of the power sources.
Q6	This game leads to an understanding of the importance of determining the best mix of power sources.
Q7	This game would be an effective tool for "energy and environmental education" in high schools or universities.
Q8	What do you think about the advantages and disadvantages of the power sources in the game?
Q9	What is the most appropriate ratio of the power sources to win the game?

It should be noted that what Q9 asks is not the proper ratio of power sources in Japan but the ratio the respondent thinks most appropriate to win the game. This is because a preliminary survey in this study revealed that if respondents were asked to answer a proper ratio of power sources in Japan, they were prone to answer with their subjective opinions on the ratio they think preferable regardless of whether they think the ratio is reasonable or feasible. Studies so far have revealed that emotional factors, such as trust [22,23], have a somewhat large effect on attitudes toward power sources, especially nuclear power [24,25]. These indicate that asking about the ratio of power sources in Japan would not confirm respondents' understanding of the best mix of power sources. Therefore, this study attempted to confirm more objective opinions of respondents, namely the ratio that the respondents consider to be reasonable when a country faces a certain situation modeled by the game. For this reason, this study abandoned performing pre- and post-tests to confirm the change in the respondents' opinion about the proper ratio of power sources. Instead, this study evaluated whether respondents answered a ratio that they thought reasonable based on their answers to Q8 and the additional open-ended questions.

The dependence of the respondents' answers to Q1–7 on their gender, grade, major, ranking in the second game, and the moderator with whom they played the game were evaluated using the two-sided Fisher's exact test. For example, the null hypothesis of the test was, "There is no difference between males and females in their answers to Q1." Answers to Q9 were analyzed using the Kolmogorov–Smirnov test (if there were two groups) or the Kruskal-Wallis test (if there were more than two groups) in the same manner. Because most of the respondents majored in engineering or education, two cases were assessed to evaluate the dependence on the major: all the five majors in Table 3 and only engineering and education. The five respondents whose attributes were unknown were excluded from the tests. The four respondents who played the game with two moderators were excluded to evaluate the dependence on moderators. No statistical test was performed to evaluate the dependences on age, the number of moderators with whom the respondents played, whether the respondents had played the game before, or whether the "nuclear accident event" happened during the game because of their small frequencies. The effect sizes used were the absolute values of Cliff's delta (d) and eta squared (η^2) for two and more than two groups, respectively. These tests as well as the calculation of the effect size were conducted using R version 4.3.0.

3. Results

Among the 18 groups, 16 drew the "nuclear accident event card" at least once. All of them evaded the event (see Appendix A.1 (5) for more details). This means that none of them actually faced a "nuclear accident" that imposed a large burden on the players with nuclear power facilities, while most of the respondents recognized that there is a small possibility of a nuclear accident.

Table 5 summarizes the respondents' answers to Q1–Q7. Almost all the answers to Q1 were either 6 or 7, which indicates that the respondents evaluated the game as very enjoyable. This was also confirmed in the answers to the additional questions requesting comments on the game; quite a few respondents wrote that "I enjoyed this game very much". The answers to Q2–Q6 were comparable to or somewhat more positive than those in the earlier study, thus supporting the improvement of the game. The two very negative answers to Q3 and Q6 (=1) were made by respondents who played the game at moderator #1's first facilitation. This indicates that moderator's skill is an important factor in facilitating the game, which is consistent with this well-known fact in the utilization of gaming in education. It should be noted, however, that even those whose answers to Q3 were negative thought the game was enjoyable (=6 or 7). The reason why their answers to Q6 were very negative (=1) cannot be ascertained, as they did not point out something specific in the answers to the additional questions. Notably, most of the answers to Q4 and Q7 were very positive, which supports the idea that the proposed game could be a good educational tool for thinking about energy and electricity.

Table 5. The numbers of respondents' answers to Q1–Q7.

	Q1	Q2	Q3	Q4	Q5	Q6	Q7
1: Strongly disagree	0	0	2	0	0	2	0
2: Disagree	0	0	4	0	0	1	1
3: Somewhat disagree	0	5	8	2	1	2	2
4: Neither agree nor disagree	0	4	6	1	2	8	1
5: Somewhat agree	1	11	17	6	8	5	7
6: Agree	14	26	9	11	20	20	13
7: Strongly agree	35	4	4	30	19	12	26

Table 6 presents the results of the Fisher's exact test and the calculated effect sizes. No statistical significance ($p < 0.05$) was confirmed in almost all the cases. This indicates the answers to Q1–Q7 were independent of the attributes of the respondents. In contrast, the dependence of the answers to Q3 on the moderator was statistically significant and had a somewhat large effect size ($\eta^2 = 0.21$), which would be reasonable, as the moderator's skill in facilitating should affect the ease of understanding the rules of the game.

Table 6. The *p*-values and the effect sizes (in the bracket) of the effect of the factors.

	Q1	Q2	Q3	Q4	Q5	Q6	Q7
Gender	1 (0.05)	0.12 (0.46)	0.57 (0.03)	0.81 (0.06)	0.45 (0.06)	0.94 (0.01)	0.78 (0.12)
Grade *	1 (0.03)	0.35 (0.01)	0.01 (0.01)	0.62 (0.05)	0.25 (0.01)	0.03 (0.01)	0.65 (0.03)
	1 (0.07)	0.41 (0.15)	0.01 (0.20)	0.44 (0.33)	0.20 (0.17)	0.03 (0.08)	0.48 (0.01)
Major **	0.34 (0.01)	0.31 (0.12)	0.76 (0.04)	0.48 (0.06)	0.64 (0.06)	0.96 (0.04)	0.87 (0.04)
	1 (0.05)	0.34 (0.39)	0.39 (0.08)	0.92 (0.04)	0.54 (0.16)	0.65 (0.13)	1 (0.09)
Ranking	0.74 (0.05)	0.92 (0.00)	0.98 (0.06)	0.25 (0.02)	0.96 (0.07)	0.61 (0.03)	0.35 (0.03)
Moderator	0.92 (0.07)	0.07 (0.13)	0.01 (0.21)	0.74 (0.00)	0.70(0.00)	0.45 (0.10)	0.38 (0.11)

* Upper: all the grades were considered; lower: only bachelor and master grades were considered. ** Upper: all the majors were considered; lower: only engineering and education were considered.

The respondents' answers to Q8 were consistent with the characteristics summarized in Tables 1 and 2. Because the questionnaire assumed that the respondents would answer the question just in one or two sentences, the answers were rather qualitative (e.g., "Coal-fired power generates a large amount of GHG; its fuels are cheap and abundant"). There was no obvious misrecognition of the characteristics of the power sources, such as "Coal-fired power generates less GHG than oil-fired power". This would support that the respondents answered with rational ratios as their answers to Q9 based on the correct understanding of the characteristics of each energy source.

Table 7 summarizes the respondents' answers to Q9. The answers from two of the respondents (male, bachelor's student of engineering) were excluded from calculating the statistics in the table because they did not answer with the ratios of the seven power sources individually. Two other respondents identified the ratios not by specific values but by ranges (e.g., "from 10% to 20%"). In such a case, calculating the statistics involved replacing the range with the mean of the upper and lower bounds of the range. The statistics shown in the table indicate that the respondents thought that it was reasonable to use gas-fired power, nuclear power, and hydropower as major power sources. Notably, the mean values of the ratios are quite similar to the actual Japanese ones in 2010, as shown at the bottom row of the table [26], except for coal-fired power and hydropower. The reason why the 2010 data were used for the comparison is that there is a large difference between 2010 and after 2010 in the ratios of power sources in Japan due to the Fukushima accident that occurred in March 2011. All nuclear power plants in Japan stopped their operations after the accident, and very severe regulations were imposed on their restart. Consequently, the ratio of nuclear power in Japan is no more than several percent since 2011, although it was more than 30% in 2010, as shown in Table 7. In contrast, there were not very large changes in the ratios of power sources in Japan from 2000 to 2010. In addition, the increase in domestic power demand in the last two decades in Japan is less than 10%. These imply that it would be reasonable to regard the ratios in 2010 as reasonable ones from the viewpoint of energy and the related issues Japan faces. The respondents may have been reluctant to use coal-fired power facilities because the restrictions on GHG emissions are the largest difficulty they faced in satisfying electricity demand. In contrast, the game design dictates that hydropower is a powerful source with almost no disadvantages. Furthermore, even the weakest hydropower in the game can generate approximately twice the actual annual power generated by the largest hydropower station in Japan to make the game enjoyable. It is probable that these are the major reasons why the respondents preferred hydropower. The aforementioned surveys by Japan Atomic Industrial Forum reported that about half of university students in Japan insisted on using solar and wind powers as much as possible, and the majority preferred not using or refraining from using nuclear power as a national power source 30 years later [2], which is consistent with another public survey targeting people with more varieties of demographic backgrounds [27]. Another survey targeting only students studying at the School of Engineering, Tohoku University reported a similar result, whereas their answers were less negative concerning nuclear power [28]. Therefore, the ratios in the table imply that the game would be an effective tool for understanding the validity of a national power policy, although the game significantly simplifies the actual situation. An earlier preliminary study of the authors performed a similar evaluation using a previous version of the game that did not consider the possibility of nuclear accident, and the ratio of a nuclear power that respondents preferred was about 50%. It is not reasonable to conclude that the decrease in the ratio is due to the implementation of nuclear accidents because the difference between the two versions of the game is not limited to the presence of the nuclear accidents. It is interesting that implementing the nuclear accident event, which actually did not happen, decreases the ratio by almost 20%. This could imply the possibility of using a game to quantitatively evaluate the relationship between public acceptance of nuclear power.

Table 7. Statistics of respondents' answers to Q9 (unit: %).

	Coal-Fired	Oil-Fired	Gas-Fired	Nuclear	Hydro	Solar	Wind
Mean	11.5	9.0	22.1	28.6	22.1	3.9	2.8
Std.	10.7	7.2	11.9	14.6	11.6	6.8	4.4
Min.	0	0	5	0	0	0	0
Q_1	0	0	10.75	20	14	0	0
Q_2	10	10	20	25	20	0	0
Q_3	16	13	30	40	30	5	5
Max.	40	25	70	60	70	40	20
Japan 2010	23.8	8.3	27.2	30.8	8.7 *1	1.2 *2	

*1 including pumped-storage hydro (0.9%). *2 This value is about "new power sources.".

The results of the test to evaluate the effect of the factors on the respondents' answers to Q9 are summarized in Table 8. No statistical significance was observed in most cases. The statistical tests revealed that the ratios of solar and wind powers were dependent on the respondents' gender and major. Specifically, approximately 70% of the male respondents answered that the ratios of solar and wind powers should be zero, whereas 4 of the 14 female respondents answered that they should be zero. Similarly, 11 of the 12 graduate students and 21 of the 26 respondents majoring in engineering indicated that the ratios should be zero, which would be the major reason for $p < 0.05$ in the dependence of the answer on each respondent's grade and major. However, it would go too far to conclude that female respondents or those who majored in non-engineering fields preferred solar and wind power because they indicated that the ratios should be as small as 5%, as shown in Table 7. The mean values of the ratios of hydropower as given by male and female respondents were 22.6 and 19.6%, respectively; those given by respondents majoring in engineering and education were 25.3 and 18.4%, respectively. Evaluating the reasons for these results would require further investigation with more respondents.

Table 8. The *p*-values and effect sizes (in brackets) of the respondents' answers to Q9.

	Coal-Fired	Oil-Fired	Gas-Fired	Nuclear	Hydro	Solar	Wind
Gender	0.35 (0.05)	0.91 (0.00)	0.34 (0.15)	0.82 (0.04)	0.06 (0.35)	0.00 (0.40)	0.04 (0.31)
Grade *	0.15 (0.04)	0.79 (0.04)	0.67 (0.03)	0.89 (0.04)	0.82 (0.04)	0.08 (0.07)	0.02 (0.13)
	0.21 (0.24)	0.59 (0.08)	0.62 (0.07)	0.46 (0.07)	0.80 (0.05)	0.03 (0.38)	0.01 (0.45)
Major **	0.78 (0.06)	0.94 (0.08)	0.17 (0.06)	0.69 (0.04)	0.05 (0.14)	0.01 (0.24)	0.02 (0.21)
	0.33 (0.08)	0.51 (0.05)	0.39 (0.12)	1 (0.02)	0.03 (0.40)	0.00 (0.55)	0.00 (0.46)
Ranking	0.17 (0.05)	0.22 (0.03)	0.01 (0.20)	0.99 (0.07)	0.01 (0.23)	0.32 (0.01)	0.94 (0.06)
Moderator	0.22 (0.06)	0.43 (0.00)	0.28 (0.04)	0.20 (0.07)	0.77 (0.07)	0.75 (0.07)	0.44 (0.00)

* Upper: all the grades were considered; lower: only bachelor and master grades were considered. ** Upper: all the majors were considered; lower: only engineering and education were considered.

4. Discussions

4.1. Analyzing the Results Obtained in This Study

An earlier study reported that Japanese university students who played a serious digital game that simulated energy production and conservation strategy in an urban city had a positive perception toward nuclear energy [29]. In general, digital games are able to simulate complicated issues, and thus, they are suitable for the realistic modeling of national power supply problems. It would be reasonable that the Japanese university students realized the importance of nuclear power to supply a sufficient amount of electricity after playing the digital game that simulated the real situation where nuclear power is actually utilized. On the other hand, non-digital games are much inferior to digital ones in the capability to simulate complicated situations. Whereas another recent study reported a non-digital game design for discussing proper energy systems that accommodate the request from society and stakeholders [30,31], it did not necessarily intend to simulate the actual situation. In contrast, this study demonstrated a non-digital board game design that would lead to a better understanding of the characteristics of power sources and the validity of a national power mix by another approach.

The most probable reason why the game worked is that the respondents virtually faced the national power supply problem and related issues through the game. To discuss the proper power ratio as a country, it is indispensable to have a big picture of the problem. This is exactly what participants experience in the game. The respondents were required to make their decisions to satisfy power demands based not on somebody's opinion but on more objective information on the characteristics of each power source, such as its output, cost, and uncertainty. Analyzing the answers to the additional open-ended questions indicated that using the realistic units (JPY) and figures (such as TWh) was effective in helping the participants see the big picture rather realistically. It is usually difficult to realize the magnitudes of figures used in discussing power demands and supplies; however, participants can realize them naturally by playing the game. It should be noted that quite a few respondents complained that the solar and wind powers were too weak, and they needed to gather many cards to generate a sufficient amount of electricity in the game, which would support that the respondents understood the difficulty in supplying electricity using only these two power sources.

4.2. The Effect of the Randomness of the Game

As the respondents played the game only twice, it would be probable that the answers of the respondents were affected by the randomness of the game. However, the statistical tests did not confirm the effect of a moderator on almost all the answers except Q3, which asked about the complexity of the rules of the game. Because different moderators indicate different games, it is reasonable to postulate that the effect of the randomness on the answers was negligible in this study.

4.3. Debriefing

In this study, debriefing, which plays a critical role in game-based learning [32], was performed in a simple manner, as mentioned in Section 2.2. This is primarily because the authors refrained from contacting the respondents until they finished filling out the questionnaire to avoid biasing their answers. It was improper to let the moderator organize the debriefing, as the moderators did not have sufficient knowledge to do it. This would indicate that with a more proper debriefing, such as a face-to-face explanation by a trained lecturer or discussion between participants, this game would be a more effective tool for teaching and learning.

4.4. Limitations of This Study

There are several limitations of this study. The largest one is that the questionnaire survey in this study did not ask for "the best mix of power sources in Japan" but "the best mix of power sources to win the game". In addition, this study did not measure the changes in the knowledge or attitudes of the respondents before and after the game due to the reason explained in Section 2.3. Thus, the results obtained in this study rather indirectly support the notion that the game can enhance public acceptance of a national power policy. In addition, as the game was designed so that it is used in a class at the higher education level, whether the game works effectively in another situation is yet unclear. Further research is needed to determine whether this approach can be used effectively in other contexts or if it leads to a better understanding of national power policy beyond just understanding the characteristics of different power sources.

5. Conclusions

This study has demonstrated a non-digital board game design that would be an effective tool for teaching and studying a national power policy. A board game to understand the characteristics of power sources from a Japanese viewpoint was developed based on an earlier study by the authors. A total of 50 undergraduate and graduate students were recruited to assess the game. The results of the questionnaire-based survey conducted after the game confirmed the students' evaluation that the game was highly enjoyable and would be an effective tool for "energy and environmental education" in high schools or universities. In addition, the average answer to "What is the most appropriate ratio of power sources to win the game?" was similar to that of Japan before the Fukushima disaster, although the game significantly simplified and even ignored various factors affecting the national policy of power sources.

This study did not confirm that the answers depended on the attributes of the respondents. However, it should also be pointed out that the attributes of the respondents in this study (undergraduate or graduate students at two closely located universities) are rather limited. Many studies have concluded that many factors such as gender [33–35], age [36,37], educational background [38–41], and inhabiting area [42,43] affect attitudes toward energy and electricity. Thus, performing the same survey but with respondents having completely different backgrounds could lead to quantitatively different results. This could also imply that the game would contribute to the evaluation of factors affecting the attitudes toward a national power policy.

Author Contributions: Conceptualization, N.Y. and R.H.; methodology, N.Y.; validation, N.Y.; formal analysis, N.Y.; investigation, N.Y.; data curation, N.Y.; writing—original draft preparation, N.Y.; writing—review and editing, R.H.; project administration, N.Y.; funding acquisition, N.Y. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: Ethical review and approval were waived for this study because this study did not attach any instruments to the respondents, impose any physical or psychological stress on the respondents, or gather any information to identify the respondents.

Informed Consent Statement: Informed consent was obtained from all the respondents and moderators involved in the study.

Data Availability Statement: The data and the latest version of the game are available upon a reasonable request to the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Appendix A

This appendix explains the details about the game so that readers can have a clearer image of it. As the purpose of the article is not to offer instructions on how to play the game itself, explaining the full detail of the game is avoided. The authors are pleased to offer the complete information necessary to play the latest version of the game upon request.

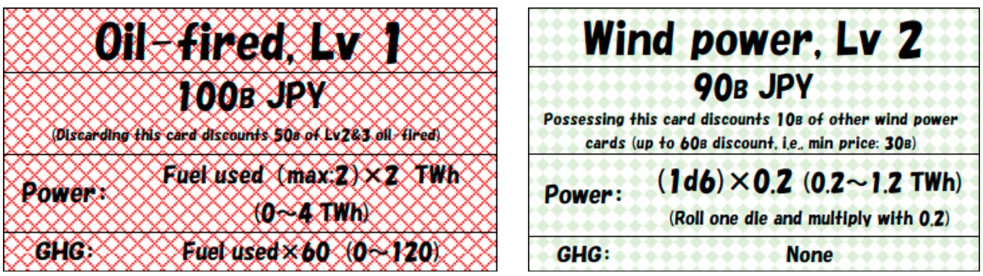
Appendix A.1. Items Used in the Game

(1) Power generation facility card

In this game, a power generation facility is represented by a card, as shown in Figure A1. The front of the card shows the type and level of the power generation facility, the price, the amount of power it can generate, and the amount of greenhouse gas emissions. The level of a facility generally ranges from one to three, in which the higher the level, the larger the output of the facility. There is no Level 1 nuclear power; wind and solar powers have only Level 2. The players purchase power generation facility cards during the game; they can own as many power generation facility cards as long as they can afford; however, the number of cards in the game is limited.

There are seven types of power generation facilities, as summarized in Table 1. Coal-, oil-, and gas-fired power generation facilities require resources to generate power, and their outputs are proportional to the amounts of resource inputs. Whereas nuclear power also requires resources to generate power, its output and the amount of resources needed for power generation are constant. The amounts of electricity generated by wind and solar power are determined by the rolled dice in every round. The number of dice rolled is one for wind and two for solar, regardless of the number of cards. That is, a player having three Level 2 wind power cards rolls one die and multiplies the results by 0.6 (=0.2 × 3) to decide the amount of power to be generated.

The prices of power generation facilities are basically based on the recent levelized cost of electricity in Japan. Specifically, the price of Level 3 nuclear power, which can generate 12 TWh, is set to JPY 600 billion. The prices of other facilities are decided based on their corresponding outputs and the ratios of their initial costs with those of nuclear power in the levelized cost. The price of gas-fired power generation facilities is adjusted to make them more expensive, while those of solar and wind power are cheaper than the actual ones to balance the game. More specific information on the facilities is summarized in Tables A1 and A2.



(**a**) Level 1 Oil-fired power facility card. (**b**) Level 2 Wind power facility card.

Figure A1. Examples of power generation facility cards.

Table A1. Maximum output of power generation facilities (unit: TWh).

	Level 1	**Level 2**	**Level 3**
Coal-fired *1	4	8	12
Oil-fired *1	4	8	12
Gas-fired *1	4	8	12
Nuclear *1	N/A	8	12
Hydropower	2	4	6
Solar	N/A	1.2 *2	N/A
Wind	N/A	1.2 *3	N/A

*1 Generating 2 TWh requires one resource. *2 Two dice rolls × 0.1 TWh. *3 One dice roll × 0.2 TWh.

(2) Dice (four colors × 20 for representing the resources + another color × 4–8 for random number generation)

The four colored dice are used to represent the four resources, respectively, and the other dice are used to generate various random numbers. For the dice representing resources, the color of the dice represents the type of resource they represent (blue: coal, red: oil, purple: gas, yellow: uranium), and the eye of the dice represents the amount of resources. The price of a resource, shown on the mainboard, is the price of one die, and it is independent from the eye. Thus, dice with six eyes and dice with one eye are six times different in value. The prices of the resources and their fluctuations are based on the actual fuel and other operation costs in the levelized cost of electricity in Japan and the change in the spot prices of the resource in the last several decades.

Table A2. Price of power generation facilities (unit: billion JPY).

	Level 1	**Level 2**	**Level 3**
Coal-fired *1	80	160	240
Oil-fired *1	100	200	300
Gas-fired *1	90	150	200
Nuclear *1	N/A	400	600
Hydropower	100	200	300
Solar	N/A	100 *1	N/A
Wind	N/A	90 *2	N/A

*1 Possessing one solar power card decreases the price by JPY 20 billion (minimum price is JPY20 billion). *2 Possessing one wind power card decreases the price by JPY 10 billion (minimum price is JPY 30 billion).

(3) Mainboard

The mainboard, shown in Figure A2, is an A3-sized sheet placed at the center of the field during the game. It is to clearly show important information: the number of rounds in the game, each player's development level, power requirements, the maximum fuel (number of dice) one can possess, GHG emission limits, resource prices, and the order of purchases for that round.

Round	①	②	③

Level	Power Needed (Max. Fuel)
1	6.5 TWh (3)
2	12.0 TWh (4)
3	15.5 TWh (4)
4	20.0 TWh (5)
5	23.0 TWh (5)
6	30.0 TWh (6)
7	34.0 TWh (6)
8	37.0 TWh (7)
9	40.0 TWh (7)
10	46.0 TWh (8)

Order	1	2	3	4

GHG limit
300
350
400
450
500
550
600
650
700
750
800

Coal (to6@Phase8)	Oil (+2@Phase8)	Gas (+2@Phase8)	Uranium (to6@Phase8)
15	30	20	10
20	40	25	15
25	50	30	10
20	40	25	15
15	30	20	10
20	40	25	15
25	60	35	10
15	50	30	15
30	80	40	10
25	100	50	20
30	120	60	15
35	140	70	20
40	80	80	15
60	300	120	20

Figure A2. Mainboard.

(4) Investment card

An investment card can be obtained at the auction held in each round and has various positive effects, as presented in Figure A3. Some cards are useful for interfering with other players' strategies. For example, the "global warming countermeasure" card can decrease all players' GHG limits by 50 or 100, while the "tightening of regulation" card can remove up to four power generation facility cards from the field. Some cards provide additional scores at the end of the game.

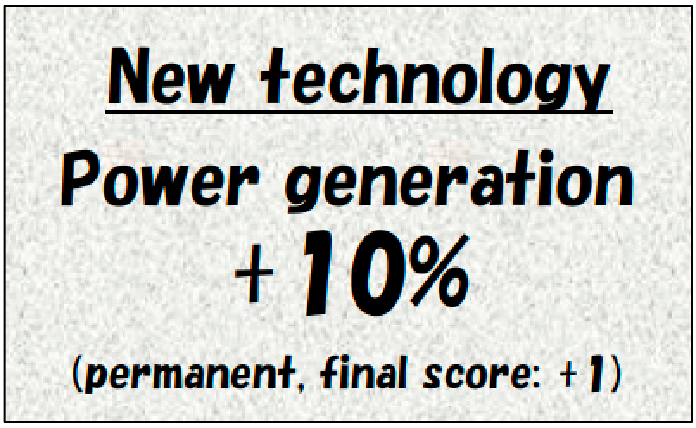
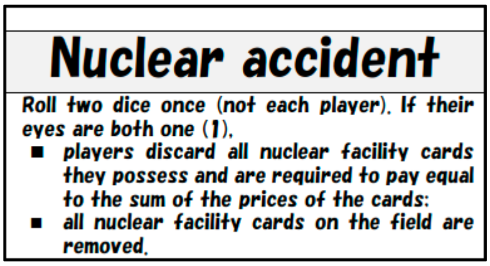


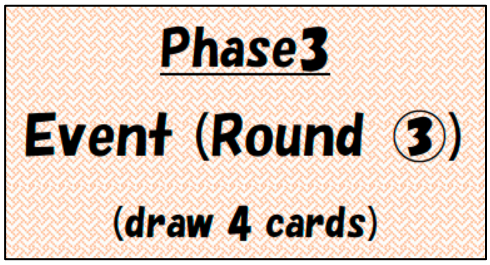
Figure A3. Example of an investment card.

(5) Event card

Event cards are used for triggering events. There are ten event cards for each round, namely 10 × 3 = 30 cards. Most events provide either a positive or negative effect on a specific power generation facility or resource, such as increase or decrease in the price of oil. One of most important event cards is the "nuclear accident" shown in Figure A4. This card appears in the third round with a probability of 75%. When this card appears, two dice are rolled to evaluate whether something serious will happen. If their eyes are both one (thus about once in 50 games), all players must discard all the nuclear power facility cards they possess and are required to pay equal to the sum of the prices of the cards. Players with "nuclear safety measure" investment cards can reduce this possibility to 1/6 per card. That is, a player with two nuclear safety measure investment cards can evade this effect unless the eyes of an additional two dice rolls are both one (a probability of about once in 1800 games, which would be negligibly small for a player). The players are given an overview of possible events, including the nuclear accident, prior to the start of the game.



(**a**) front



(**b**) back

Figure A4. Example of an event card ("nuclear accident" card).

(6) Chips and debt cards

Chips confirm the funds owned by each player. The authors used ordinary casino chips, but any chips or even other items may be used if they can represent up to JPY 1 trillion with a minimum unit of JPY 5 billion. Debt cards, shown in Figure A5, show a player's debt, which can be paid in JPY 100 billion increments at any time in the game. When borrowing money, a player receives a JPY 100 billion debt card and JPY 50 billion in cash at the same time (100% interest is accrued immediately).

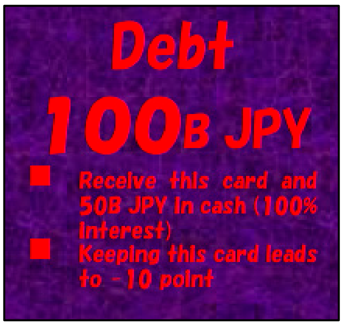


Figure A5. Debt card.

(7) Rule card

The rule card, shown in Figure A6, is an A5-size document with a summary of what to do on each round on the front and supplementary rules on the back. One copy is given to each player.

Appendix A.2. Procedure

Prior to the start of the game, players perform the following to prepare for the game:

(1) Each player receives one card for each of the following power facility cards: Level 1 coal-fired power, Level 1 oil-fired power, Level 1 gas-fired power, and Level 1 hydropower;
(2) The remaining power generation facility, investment, and event cards for each round are individually shuffled to create five piles;
(3) Eight power generation facility cards are drawn from the pile to finally line up eight types of (not eight) power generation facility cards in the field;
(4) The mainboard is placed at the center of the field. A die is rolled four times to determine the prices of the coal, oil, gas, and uranium for the first round, and marks are placed at the fuel price table of the mainboard according to the rolled die;

(5) Six dice for each color are arranged in the field to represent the resources. The eyes are random;
(6) Players place their pieces at the "GHG limit" row of the main board to indicate that their GHG emission limit is 600;
(7) Players determine the purchase order for the first round according to the dice roll (the highest roll goes first). Each player's pieces are placed in the purchase order at the top of the mainboard. The 1st/2nd/3rd/4th players in the order of purchase receive JPY 500/520/540/560 billion, respectively;
(8) Players decide the development level in the first round from 1 to 4 and then place their pieces on the line of the corresponding development level on the left side of the mainboard. Those who chose Levels 1 and 2 increase their GHG limit by 200 and 50, respectively; they move their pieces to the "GHG limit" row to represent this.

Subsequently, the players start the game. "One round" of the game consists of the following nine phases. An overview of what players do in the phases is described below.

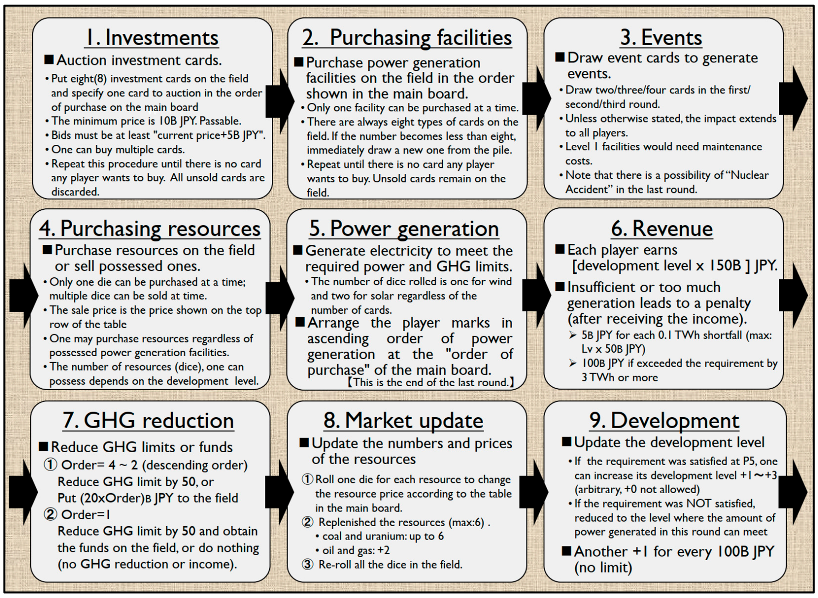


Figure A6. Rule card.

Appendix A.2.1. Phase 1: Investment

Six investment cards are drawn from the pile and placed on the field. Players auction them until there is no card in the field, or there are no more cards any player wants to buy. All unsold cards are discarded. There is no limitation on the number of investment cards a player can obtain or possess.

Appendix A.2.2. Phase 2: Purchasing Power Generation Facility

Players purchase power generation facilities on the field one by one (multiple purchases cannot be made at the same time) in the order shown on the mainboard. There should always be eight types of (not eight total) power facility cards; if there are fewer than eight, a new one is drawn immediately from the pile. This is repeated until all the players have bought the cards they want to purchase in the field.

Appendix A.2.3. Phase 3: Event

Event cards are drawn from the pile to generate events. Two, three, and four event cards are drawn from the pile at the first, second, and third rounds, respectively. Unless otherwise stated, the impact extends to all players.

Appendix A.2.4. Phase 4: Purchasing Resources

Players purchase resources in the field or sell possessed resources to the market (field) in the order shown on the mainboard. Only one die can be purchased at a time, but selling more than one die is permitted. Players may purchase any resources regardless of the power generation facility they own, but the maximum number of resources, namely dice, they can possess depends on their development level, which can be increased with an investment card.

Appendix A.2.5. Phase 5: Power Generation

Players generate electricity to meet the required power and GHG emission limits by combining the power generation facility cards and the resources that they own. Power generation facility cards are available multiple times, while resources are consumables. Coal-, oil-, and gas-fired power plants emit 40, 30, and 20 GHG, respectively, per TWh of electricity generated. Thus, if the GHG limit is 600, for example, coal-fired power plants alone can generate only 15 TWh. After all players finish the power generation, the player marks are arranged in ascending order of power generation in the "order of purchase" on the mainboard. This is the end of the third round, which signals that the scores should be calculated.

Appendix A.2.6. Phase 6: Revenue

Each player earns (150 billion $\times$ development level) JPY. Those whose power generation at Phase 5 is less than the required power must pay JPY 5 billion to the bank for each 0.1 TWh shortfall after receiving income, while those whose power generation exceeds the power required by 3 TWh or more have to pay JPY 100 billion to the bank.

Appendix A.2.7. Phase 7: GHG Reduction

Players whose purchase order is not first will reduce their GHG limit by 50 or pay purchase order $\times$ JPY 20 billion to the bank. A player in the first purchase order can choose not to reduce the GHG limit or reduce the GHG limit by 50 and receive the whole amount of money that the other players paid.

Appendix A.2.8. Phase 8: Resource Market Update

One die for each resource is rolled to change the resource price; the marks on the fuels price table are moved downwards according to the dice roll. Coal and uranium are then replenished until there are six, and oil and gas are replenished by two (but the maximum number of dice in the field per resource type is six). Then, all the dice in the field are rolled again.

Appendix A.2.9. Phase 9: Development

Players whose power generation in Phase 5 satisfied the power requirement increase their development levels from +1 to +3 from the current level (+0 is not allowed). The development levels of players who failed to satisfy the requirement will be reduced to the level at which the amount of power generated in this round can meet the required power. In addition, players can increase their development level by another +1 for every JPY 100 billion they pay (no upper limit).

Appendix A.3. Score Calculation

Once Phase 5 of the third round is finished, the scores of players are calculated as follows: (Development Level) $\times$ 5 + (owned fund in billion JPY)/50 + (sum of the levels of owned power generation facilities, excluding level 1 facilities for solar and wind powers). Players who chose development Levels 1 and 2 at the beginning of the game obtain additional scores of 10 and 3, respectively; several investment cards provide other additional scores. In contrast, players whose power generation in Phase 5 of the third round did not satisfy the demand are penalized by -10 for each 0.1 TWh shortfall. Those who have unpaid debts are also penalized by -10 for each JPY 100 billion. After computation, the player with the highest score becomes the winner of the game.

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