Economic Growth, Resources and the Environment:
The Use of Fossil Fuels in Japan's Post-war Industrialization*

SHIMANISHI Tomoki**

Introduction

The use of natural resources, particularly their efficient and rational use, generally promotes economic growth. For example, the maximization of the yields of natural resources contributes to their long-term use because it delays their exhaustion. An increase in resource productivity also makes it possible to provide goods and to generate energy at low cost. On the other hand, as W. S. Jevons shows, the efficient and rational use of natural resources sometimes destroys the environment[1]. Moreover, in the case of metal mines in early modern Japan, the maximization of their yields has also done the same. In short, there are complex relationships among economic growth, resources and the environment[2].

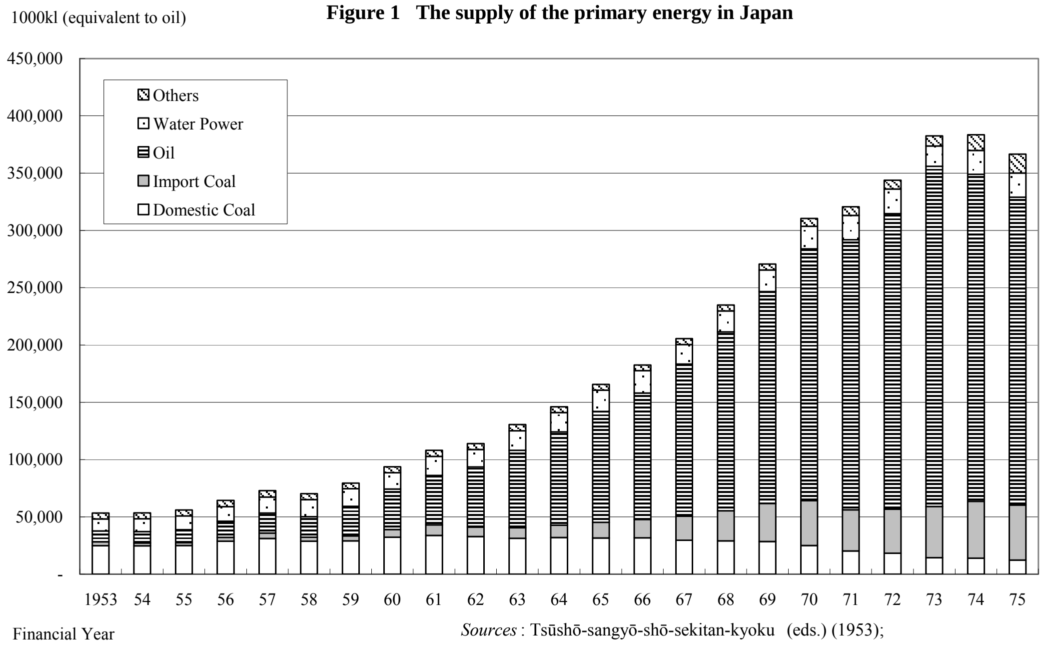
Therefore, this paper examines the use of fossil fuels, especially domestic coal, and its industrial and environmental impact in post-war Japan, and analyzes the complex relationships between coal's organic efficiency (yield of coal), resource productivity, environmental loads and economic growth. The following are the reasons for focusing on domestic coal. Needless to say, the post-war Japanese economy was affected by heavy environmental loads caused by the massive combustion of heavy oil, which was brought about by 'the energy revolution'. However, as **Figure 1** shows, the supply of domestic coal accounted for a constant amount until the end of the 1960s, although it was becoming much less than that of heavy oil. This suggests that the environment was severely damaged by the combustion not only of heavy oil but also of domestic coal, and that both the consumers and suppliers of coal had to tackle the improvement of its organic efficiency and/or resource productivity in order to cut production costs.

---

* I would like to thank Professor Kanda Sayako for her support and valuable suggestions on the earlier drafts of this paper. I am also grateful to Professor Sugihara Kaoru and other participants at the Asian International Economic History Workshop at Matsuyama University on 29 September 2008.
** College of Economics, Rikkyo University, 3-34-1 Nishi-Ikebukuro, Toshima-ku, Tokyo 1718501, Japan. Email: shimanishi@rikkyo.ac.jp

[1] Murota (2006), pp. 330-331.
[2] Okada (1999), pp. 59-88.

Figure 1 The supply of the primary energy in Japan



Sources : Tsūshō-sangyō-shō-sekitan-kyoku (eds.) (1953);
Tsūshō-sangyō-shō-daijin-kanbō-sōgō-enerugii-seisaku-ka (eds.) (1966－1973).

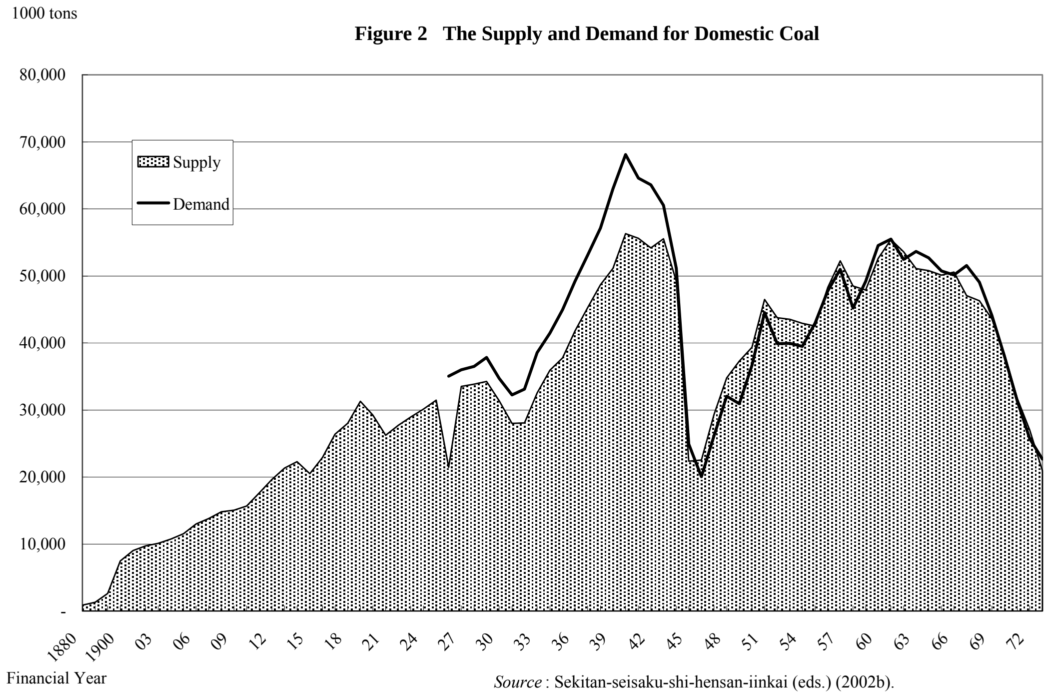
The studies by both Yada and Shimanishi demonstrated the processes in the development of domestic coal resources by the coal mining companies, and Kobori analyzed the characteristics of Japan's energy policy in the 1950s in his recent paper[3]. However, none of these authors mentioned the environmental loads caused by the use of fossil fuels, although they showed the changes in the organic efficiency and/or resource productivity in order to cut production costs. On the other hand, studies on environmental history have shown that both industrialization and economic growth have caused many types of environmental pollution[4]. However, they do not seem to be concerned about either the organic efficiency or the resource productivity of fossil fuels. This paper reconsiders these studies from the viewpoint of an economic history of the environment[5].

Many historical studies on 'the commons' analyze the complex relationships among the use of natural resources, environmental loads and economic growth in an economy that is dependent on biomass energy resources[6]. These studies demonstrate that their efficient and

---

3 Yada (1975); Shimanishi (2005), pp. 25-46; Kobori (2005), pp. 47-69.
4 Ui (eds.) (1985); Kamioka (1987); Iijima (2000).
5 For details, see Kanda (2007), pp. 3-11.
6 For details, see Mamiya (2002); Murota and Mitsumata (2004); Mitsumata, Morimoto and Murota (eds.) (2008).

Figure 2 The Supply and Demand for Domestic Coal



Source : Sekitan-seisaku-shi-hensan-iinkai (eds.) (2002b).
Note : Until 1946, a demand for import coal is added to that for domestic coal.

rational use generally contributes to environment-friendly economic growth. This paper, which focuses on the economy and on fossil energy resources, reaches a different conclusion.

Industrial and environmental changes caused by 'the energy revolution'

Problems of industrial smoke and mine pollution before the mid 1950s

Japan's industrialization after the end of the 19th century was deeply dependent on coal[7] as its primary energy resource, and the supply of coal increased from year to year[8] (see **Figure 2**). This created the environmental problem of smoke. In the case of Osaka city[9], which was known as '*Kemuri no Miyako*' [the city covered with smoke], we analyze the relationships among the use of coal, environmental loads and economic growth in the early 20th century[10].

From around 1900, increasing smoke became a problem of public concern as large-scale factories became concentrated in Osaka and burnt coal. The Osaka prefectural government set up a research committee on the regulation of smoke in 1911, and in 1913, it drafted a smoke regulation law that obliged factories to install smoke removal devices. However, this law was not

[7] In this section, 'coal' means both domestic and import coal.
[8] For the location of coalfields and industrial districts, see **Appendix**.
[9] Osaka city is located in Hanshin district.
[10] For details, see Kamioka (1987); Oda (1987).

implemented due to strong objections by the industrial community. In the late 1920s, to achieve both fuel savings and smoke reduction, people in the industrial community began to tackle the complete combustion of coal and oil by employing technical guidance for fuel burning[11]. Although this was an economical way to make economic growth more environment-friendly, in the 1930s, it was gradually changed into heat control, which stressed saving fuel rather than reducing smoke[12]. In addition, there was little mention of devices for removing smoke or sulphur oxides (SOx).

Changes in the manner of washing coal also worsened the problem of smoke. To enable shipping of high-quality coal with low ash content, collieries started washing raw coal repeatedly to remove the ash that caused smoke[13]. In the 1930s, however, the situation changed unexpectedly. As the new institution of the coal trade under the controlled economy stressed the amount rather than the quality of coal, collieries began to increase the supply of low-quality coal with high ash content by washing coal insufficiently; in other words, increasing the organic efficiency[14]. Thus, the combustion of low-quality coal caused more serious air pollution.

In coalfield areas, many collieries had mined coal in an irrational manner since the end of the 19th century[15]. This had resulted not only in serious mine pollution, such as the heaps of debris, exhaustion of well water, subsidence over goaf holes and outflow of waste water from coal-washing plants, but also in the abandonment of coal resources. Therefore, the government gradually began to regulate this irrational mining that had caused the abandonment of coal in the seams. First, Kōgyō-hō [the Mining Law] was revised to embody both the absolute liability for mining pollution and the obligation to prevent pollution in advance until 1950. Second, in 1952, the government started the recovery of the damaged areas by implementing Rinji-sekitan-kōgai-fukkyū-hō [the Extraordinary Law on Coal Mine Damage Recovery]. The cost of this was paid by the expense of fees from those who had mining rights and by government subsidies.

---

[11] Kobori (2007), pp. 51-53.
[12] Kobori (2006), pp. 40-68.
[13] Horiuchi (1933), pp. 742-752.
[14] Nezu (1958), pp. 521-522. Therefore, the calorific value of coal for steam locomotives decreased from 6310 kcal in 1940 to 5960 kcal in 1944.
[15] For details, see Sekitan-kōgai-jigyōdan (1971).

Table 1 Prices Per Calolie of Heavy oil and Domestic Coal

Financial Year	Type C Heavy Oil	Domestic Coal		Spreads	
		Keihin (C.I.F.)	Kyushu (O.R.)		
	A	B	C	B-A	C-A
1953	0.86	1.02	0.75	0.17	-0.11
54	0.81	0.89	0.58	0.08	-0.23
55	0.85	0.91	0.61	0.06	-0.24
56	0.93	0.93	0.66	0.00	-0.27
57	0.96	1.05	0.77	0.09	-0.19
58	0.81	0.98	0.70	0.17	-0.11

Unit : yen/kcal
Source : Kyushu-keizai-chōsa-kyōkai (1961).
Note: 'A' is the price in Tokyo. The carolific value of domestic coal is 6200 kcal.

The findings here involve three suggestions. First, the government worked toward a solution to the problems of mine pollution. However, it was not willing to tackle the problem of smoke. Second, rational mining would contribute to both solving the problem of mine pollution and to the promotion of economic growth in terms of the sustainable use of coal resources. Finally, washing raw coal repeatedly, which meant decreasing its organic efficiency, caused not only a decrease in the smoke that covered cities, but also an increase in mine pollution; for example, the heaps of debris and the outflow of waste water in coalfield areas.

Air pollution by sulphur oxides

The supply of coal decreased rapidly soon after the Second World War due to irrational mining during the war and the return of foreign workers to their homelands. However, as a result of government-led priority allocation of funds, materials and labour force to collieries, the supply of coal started to increase again after 1947 (see **Figure 2**). This contributed to the recovery of the Japanese economy, although there remained the following problems regarding the use of coal in post-war Japan. First, a succession of strikes by labour unions made the supply of coal uncertain. Second, the price of domestic coal was becoming higher than that of heavy oil in consumption areas (see **Table 1**), because of mounting distribution costs and labour-intensive production organizations. Finally, fuel consumers realized that it was useful for saving energy consumption to burn fluid fuels such as heavy oil[16].

Therefore, from the early 1950s, fuel consumers continued to switch their fuel from domestic coal to heavy oil imported from the Middle East. This 'energy revolution' led to a drastic

[16] Kobori (2005).

Table 2 Amount of Fuel Conversion from Domestic Coal to Heavy Oil

Financial Year	Annual Amount	Total	F.Y.	Annual Amount	Total
1949	#N/A	#N/A	55	620	7,690
50	#N/A	#N/A	56	2,300	9,990
51	1,251	1,251	57	2,220	12,210
52	2,244	3,495	58	5,440	17,650
53	3,647	7,142	59	11,800	29,450
54	-72	7,070			

Unit: 1000 tons
Sources: Nihon-tekkō-renmei-sengo-tekkō-shi-hensan-iinkai (eds.) (1959);
Sekitan-seisaku-shi-hensan-iinnkai (eds.) (2002a).
Note: The data after 1955 is dependent on the latter resource.

Table 3 Fuel Price by Districts (Purchase Price by Electric Power Industry)

Financial Year	Districts	Domestic Coal	Heavy Oil	Spread
		A	B	A-B
1958	Near Coalfield	3,381	4,769	-1,388
	Others	5,027	4,659	368
	Average	4,501	4,466	35
63	Near Coalfield	2,392	2,957	-565
	Others	3,921	3,432	489
	Average	3,582	3,297	285
65	Near Coalfield	2,357	2,773	-416
	Others	4,284	3,256	1,028
	Average	3,757	3,088	669

Unit: yen/tons
Source: Shimanishi (2004).
Note: The Price of domestic includes the ash disposal costs.

decrease in the demand for domestic coal. As **Table 2** shows, by 1959, about thirty million tons of domestic coal, corresponding to about 60% of the annual output, had been replaced by heavy oil. The supply of heavy oil continued to increase, in response to an increase in the demand for primary energy during Japan's rapid economic growth until 1973 (see **Figure 1**). Moreover, as **Table 3** shows, by the end of the 1960s, the price of domestic coal even in coalfield areas, where distribution costs were very low, had become higher than that of heavy oil.
The dependence on imports in the supply of primary energy finally reached 95.9% in 1973[17]. As a result, from the mid 1950s, the primary cause of environmental loads changed from the use of domestic coal to that of heavy oil.

Interestingly, this change brought about a new relationship between the use of domestic coal and environmental loads[18]. It was triggered by the establishment of regulations on air pollution, such as some Kōgai-bōshi-jōrei [Pollution Prevention Ordinances] in 1949, and

[17] Enerugii-keizai-kenkyūsho (eds.) (1986), p. 53.
[18] For details, see Sangyō-kankyō-kanri-kyōkai (eds.) (2002), pp. 44-122.

Baien-kisei-hō [the Smoke and Soot Regulation Law] in 1962. The latter provided that the emissions of smoke, soot, SOx and sulphur trioxide (SO_3) were to be regulated in five industrial districts, and gave the government the power to order offenders to stop operating their facilities. Fuel consumers actively set up dust collectors to comply with these regulations, because the combustion of heavy oil as well as coal caused the emissions of smoke and soot. Moreover, consumers of heavy oil had to neutralize 'acid smut' (black particulate matters combined with sulphur contained in heavy oil, H_2O and ashes) by injecting ammonia into the flue gas. Thus, these regulations gradually helped to reduce 'black' smoke[19].

On the other hand, 'white' smog that contained considerable SOx created another problem of air pollution, because Middle Eastern heavy oil was a fossil fuel with a very high sulphur content. In the case of Yokkaichi city[20], which had huge petrochemical complexes, the sulphur content of Middle Eastern heavy oil was over 3%, and the SOx concentration emitted by burning this oil was between 1 and 2.5 parts par million (ppm). This was much higher than the then legal standard of SOx concentration (under 0.22 ppm), even when we consider the diffusion of SOx into the atmosphere[21].

However, large fuel consumers were not willing to reduce SOx emission, because the regulation by Baien-kisei-hō was dubious method of measuring SOx concentration and emission[22]. Therefore, as was clearly shown in the case of Yokkaichi asthma, air pollution by SOx seriously damaged not only the atmosphere but also people's health during post-war Japan's rapid economic growth.

Domestic high-quality coal as an environment-friendly energy resource

The problem of air pollution by SOx emission was becoming increasingly serious, people recognized an unexpected characteristic of domestic coal, which had caused the earlier problem of smoke. As **Table 4** shows, the arithmetical average of the sulphur content of domestic coal was 1.16%, and generally it was under 1%, with a few exceptions. This was much lower than the sulphur content of Middle Eastern heavy oil. Given that the large fuel consumers hardly reduced

[19] Tokyo-denryoku-kabushiki-gaisha-karyokubu (eds.) (1986), pp. 71-75.
[20] Yokkaichi city is located in Chukyo district.
[21] Kawana (1985), p. 10.
[22] Kankyō-chō (1969).

Table 4 Sulphur Content and Carolies of Domestic Coal by Grades

Chikuho Coalfield		
Grade	Sulphur Content	Carolie
Tagawa	0.20	5,760
Onoura Washed	0.54	5,862
Yamano	0.70	6,880
Takamatsu Washed	0.70	6,600
Namazuda Washed	0.80	6,520
Iizuka Washed	1.12	6,040
Yoshikuma Washed	1.15	7,150

Saga and Miike		
Grade	Sulphur Content	Carolie
Kishima Washed	2.27	6,900
Sakito Washed	2.32	7,590
Miike Washed	3.10	6,930

Hokkaido		
Grade	Sulphur Content	Carolie
Ponbetsu Washed	0.25	6,800
Taiheiyo	0.27	6,650
Horonai	0.30	6,700
Sunagawa	0.50	7,030
Akabira Washed	0.50	6,750

Others		
Grade	Sulphur Content	Carolie
Takahagi	0.30	5,000
Kaminoyama	0.50	5,057
Yoshima	1.90	5,300
Ube	2.20	3,640
Kashima	3.50	6,500
Over-all Average	1.16	6,283

Unit: %, kcal
Source: Tsūshō-sangyō-shō-daijin-kanbō-chōsa-tōkei-bu (eds.) (1960).
Note: Coal grade with the highest sulphur content of each of the major collieries is extracted.

SOx emission while dust collectors became more popular, it can be said that domestic coal became a more environment-friendly energy resource than Middle Eastern heavy oil.

It is not clear whether the electric power companies—the largest coal consumers—continued to maintain their coal-fired power plants. However, they continued to increase their demand for domestic coal until the end of the 1960s. Moreover, the following cases show that both these companies and the local governments knew that the amount of SOx emission by the combustion of domestic coal was less than that by heavy oil at that time. First, Chubu-denryoku[23] [Chubu Electric Power Company] organized a research committee on SOx emission by oil-fired power plants but not by coal-fired plants[24]. Second, Denpatsu [Electric Power Development Company] obtained the approval to build a new coal-fired power plant from the government of Takasago city[25] on the condition that it did not use a mixed fuel of coal and heavy oil, because the mayor of Takasago was worried more about SOx emission by its mixed combustion, rather than the smoke by the combustion of domestic coal[26]. Therefore, it is appropriate to consider that these companies had incentives to maintain their coal-fired power

[23] Chubu-denryoku is located in Chukyo district.
[24] Chubu-denryoku-kabushiki-gaisha-karyokubu (eds.) (1988), pp. 119 and 246-248.
[25] Takasago city is located in Hanshin district.
[26] Sanjūnen-shi-hensan-iinkai (eds.) (1984), pp. 201-202.

plants until they found a possible solution to the problem of SOx emission[27].

Of course, domestic coal was only relatively superior to Middle Eastern heavy oil in industrial districts where the problem of SOx emission was very serious, such as Keihin, Chukyo, Hanshin and Kita-Kyushu. The coalfield areas were generally so far from these districts that collieries had to ship high-quality coal, the price of which was expensive enough to cover these distribution costs. This caused a decrease in the organic efficiency, because it was necessary to wash the raw coal repeatedly to improve its quality. On the other hand, as the next section shows, the collieries tackled an increase in the organic efficiency in several ways.

Increase in the organic efficiency of coal and its impacts

Increase in the demand for inferior-quality coal[28]

Collieries were forced to cut their production costs as ‘the energy revolution’ proceeded. Along with the reduction of the workforce and the mechanization of production, an increase in the organic efficiency provided another effective way to cut their costs. Therefore, the collieries started to commodify inferior-quality coal, such as raw coal and low-calorie coal, which had been thrown away in the past[29].

The pioneers of this were the collieries in the Joban coalfield[30]. They planned to commodify inferior-quality coal as a fuel for thermal power generation by Tohoku-denryoku[31] [Tohoku Electric Power Company] in 1953, and in the following year, they succeeded in generating electricity by the combustion of inferior-quality coal. In 1955, Joban-karyoku [Joban Joint Power Company] was established jointly by Joban-Tankō [Joban Coalmining Company], Tokyo-denryoku[32] [Tokyo Electric Power Company], Tohoku-denryoku and so on, and in 1957, it started to operate its Nakoso Power Plant[33].

---

[27] In fact, the electric power industry’s demand for domestic coal increased from 6.7 million tons in 1955 to 25.94 million tons in 1968. For details, see Sekitan-seisaku-shi-hensan-iinnkai (eds.) (2002b).

[28] Following the then classification, we call coal with calorific value of under 3500 kcal ‘inferior-quality coal’.

[29] Low-calorie coal was partly commodified in Ube coalfield before the Second World War.

[30] For details, see Joban-kyodo-karyoku-50-nenshi-hensan-iinkai (eds.) (2005), pp. 20-25.

[31] Tohoku-denryoku is located near Joban coalfield.

[32] Tokyo-denryoku is located in Keihin district.

[33] Nakoso is located in Joban coalfield.

Table 5 Inferior-quality Coal-Fired Power Plant (Built after the 1960s)

Colliery	Company	Number of Generator	Carolie (Unit: kcal)	Built Year
Nakoso	Joban Karyoku	3	3,500	1960-61
Kanda	Nishi-nihon Kyodo	1	3,500	1963
Wakamatsu	Denpatsu	2	3,000	1963

Sources: Joban-kyodo-karyoku-50-nenshi-hensan-iinkai (eds.) (2005); Sanjūnen-shi-hensan-iinkai (eds.) (1984); Shashi-henshū-shō-iinkai (eds.) (2001); Sekitan-tsūshin-sha (eds.) (1962).

Interestingly, there was no great difference in the thermal efficiency between inferior-quality coal-fired power plants and middle-quality coal-fired power plants as a result of technological innovations in thermal power generation. For example, Nakoso power plant used coal with calorific values of 3500 kcal, and its thermal efficiency was 30.5%[34]. The Shin-Ube Power Plant of Chugoku-denryoku[35] [Chugoku Electric Power Company] used the same coal as Nakoso in terms of calorific value, and its thermal efficiency was 34.58%[36]. These figures were almost the same as the thermal efficiency of the Tanagawa Power Plant of Kansai-denryoku[37] [Kansai Electric Power Company], which used coal with calorific values of 5300 kcal[38].

Moreover, the price of inferior-quality coal was much lower than that of high-quality coal. In 1960, in the case of Kyushu-denryoku[39] [Kyushu Electric Power Company], the purchase price of inferior-quality coal with a calorific value of only 3000 kcal was 0.413 yen per kcal, whereas that of high-quality coal with a calorific value of 5500 kcal was 0.649 yen per kcal[40]. Surprisingly, this was also about 50% lower than the price of heavy oil (see **Table 1**). Of course, the active demand for inferior-quality coal was limited to consumers near coalfields, such as Kyushu-denryoku, Chugoku-denryoku and Joban-karyoku, because its price was not expensive enough to cover distribution costs. Electric power companies near coalfields thus built inferior-quality coal-fired power plants, in turn, after the 1960s (see **Table 5**).

Technical developments for increasing the organic efficiency of coal

In response to the increasing demand for inferior-quality coal in thermal power generation, the collieries actively developed techniques for supplying inferior-quality coal. First, coal washers

34 Ibid.
35 Chugoku-denryoku is located near Ube coalfield.
36 Abe (1960), pp. 127-129.
37 Kansai-denryoku is located in Hanshin district.
38 Ibid.
39 Kyushu-denryoku is located in Kita-kyushu district.
40 Sasaki (1995), p. 150.

Table 6 The Supply of Inferior-quality Coal by Takamatsu

Financial Year	Kyushu-denryoku	Chugoku-denryoku	Denpatsu (Wakamatsu)
1956	32	19	
57	13	23	
58	20	117	
59	105	282	
60	131	342	
61	89	291	
62	95	305	231
63	80	105	487
64	46	92	585
65	96		579
66	75	14	473
Total	782	1,590	2,355

Unit : 1000 tons
Source : Sasaki (1995).

for dense and medium separation were introduced for collecting inferior-quality coal from raw coal, because they made it possible to control the quality of coal more strictly than the existing coal washers who used only water[41]. Second, part of the debris or raw coal was commodified.

For example, after 1962, the Takamatsu Colliery[42] of Nihon-tankō [Nihon Coalmining Company], one of the major coal mining companies, started not only to wash raw coal slightly so as not to increase its calorific value but also to collect inferior-quality coal by re-washing debris. Furthermore, after 1963, it shipped such inferior-quality coal with a calorific value of 3500 kcal to the Wakamatsu Power Plant of Denpatsu[43]. As **Table 6** shows, after 1963, the annual output of inferior-quality coal by Takamatsu was about 600,000 tons. Takamatsu eventually shipped 4.78 million tons of inferior-quality coal to Wakamatsu, whose fuel was wholly dependent on the inferior-quality coal of Takamatsu, until its closure in 1971[44]. Incidentally, the Wakamatsu colliery[45] of Nihon-tankō used debris after re-washing as construction material for land reclamation and site preparation for housing.

On the other hand, small- and medium-sized collieries increased their supply of inferior-quality coal by mixing debris into high-quality coal. A small colliery would mix debris into high-quality coking coal, which was much more expensive than inferior-quality coal, and would ship this mixed coal to electric power plants as inferior-quality coal[46].

---

41 Mori (1998), pp. 22-26; Saito (1960), pp. 144-152.
42 Takamatsu is located in Chikuho coalfield.
43 Sasaki (1995), pp. 139-199. Wakamatsu Power Plant was located in Kita-kyushu district.
44 Sanjūnen-shi-hensan-iinkai (eds.) (1984), p. 280.
45 Wakamatsu is located in Chikuho coalfield.
46 Fukuoka-tsūshō-sangyō-kyoku (1965), p. 69.

The major collieries producing coking coal also developed these techniques. For example, the Ashibetsu Colliery[47]of Mitsui-kōzan [Mitsui Mining Company], the largest coal mining company in Japan, restructured its coal washery in 1964. This new coal washery, equipped with a Baum jig washer using water, coal washers for dense medium separation and flotation machines, enabled Ashibetsu not only to improve the quality of coking coal but also to collect inferior-quality coal. The Miike[48] Colliery of Mitsui also restructured its coal washeries after 1962 following Ashibetsu, and it succeeded in boosting the production of both high-quality coking and inferior-quality coal[49].

Needless to say, these technical developments for increasing inferior-quality coal caused the increase in the organic efficiency of coal, and this contributed to the sustainable use of coal resources. Moreover, there were also those who collected inferior-quality coal from the heaps of debris or from the waste water released by the coal washeries into the rivers near the collieries. The amount of such coal in 1966 was surprisingly 1.7 million tons, corresponding roughly to the annual output of one major colliery[50]. Therefore, an increase in the demand for inferior-quality coal contributed to reducing mining pollution such as larger heaps of debris and water pollution, which still remained a serious problem.

Serious air pollution caused by the combustion of fossil fuels

The combustion of inferior-quality coal caused four environmental loads due to its high ash content. First, smoke emission increased. However, this was not a serious problem, because it was reduced by fitting dust collectors. Second, the amount of coal ash after combustion also increased. To deal with this problem, coal consumers and collieries developed a way to commodify coal ash as a construction material, known as ‘fly-ash’, for making concrete, reclaiming land and filling goafs[51].

Third, SOx emission increased. As **Table 7** shows, the sulphur content of the debris, which was contained in inferior-quality coal, was generally higher than that in washed coal,

[47] Ashibetsu is located in the midland of Hokkaido coalfield.
[48] Miike is located in Miike coalfield.
[49] For details, see Mitsui-kōzan-kabushiki-gaisha (1963), p. 20; Mitsui-kōzan-kabushiki-gaisha (eds.) (1990), pp. 305-306; Ousaka (1989), pp. 5-7; Konishi (1990), pp. 15-17.
[50] For details, see Kyushu-denryoku-kabushiki-gaisha (eds.) (1982), p. 66.
[51] Joban-kyodo-karyoku-50-nenshi-hensan-iinkai (eds.) (2005), pp. 43-44.

Table 7 Sulphur Content of Debris and Washed Coal

Company	Colliery	Debris	Washed Coal
Kishima	Kishima	2.34-3.50	2.1-2.66
Nicchitsu	Emukae	0.54-3.62	0.7-1.5
Aso	Yoshio	0.21-0.78	0.38-0.69
Nittan	Ookimi and Takamatsu	0.495-0.819	0.3-0.7

Unit : % (the lowest－the highest)
Sources : Tsūshō-sangyō-shō-daijin-kanbō-chōsa-tōkei-bu (eds.) (1960); Santan-chiiki-shinkō-jigyōdan (eds.) (1964).

because part of the sulphur was combined with the ash on the surface of the coal. According to a trial calculation, the sulphur content of Takamatsu's inferior-quality coal was a surprising 4.78%[52]. Needless to say, the combustion of such inferior-quality coal caused more SOx emission than that of Middle Eastern heavy oil. Finally, no other fossil fuels caused more emission of nitrogen oxides (NOx) at the time of combustion than coal. That is, coal caused a NOx emission of 15.2 kg/10^7 kcal, whereas heavy oil caused an emission of 12.2 kg/10^7 kcal[53].

The problem of smoke emission and coal ash was not very serious, but the combustion of inferior-quality coal steadily worsened the air pollution resulting from SOx and NOx emissions. However, this problem went unnoticed because people were more concerned with the air pollution resulting from the massive combustion of Middle Eastern heavy oil.

Responses to a new regulation law

Stack gas purification techniques[54]

After the mid 1960s, new environmental pollution problems, such as stench, noise and eutrophication, became serious in addition to the existing air and water pollution. In 1965, the Japanese government established Kōgai-bōshi-jigyōdan [the Pollution Control Service Corporation] to implement anti-pollution projects in industrial districts where the problem of the SOx emission had become very serious. Moreover, the establishment of Kōgai-taisaku-kihon-hō [the Basic Law for Environmental Pollution Control] in 1967 served as the impetus for several regulatory laws for each problem. Taiki-osen-bōshi-hō [The Air Pollution Control Law] was established in 1968, and it was an especially important example of such laws. As the government started to regulate SOx concentration on the ground under this law[55], fuel consumers were forced

[52] Sasaki (1995), pp. 203-206.
[53] Tanaka and Yamada (1971), p. 41.
[54] For details, see Sangyō-kankyō-kanri-kyōkai (eds.) (2002), pp. 49-122.
[55] This regulation was called 'the K value regulation'. The K value indicates the SOx concentration at

to lengthen their chimneys or to reduce their SOx emission.

The regulations introduced under this law became stricter the following year. The law prescribed SOx concentrations such as 'under 0.05 ppm/h a day during over 70% of the year' and 'under 0.1 ppm/h during over 80% of operation hours'. The concentration of oxidant, which was a type of peroxide NOx that reacted photochemically, was also regulated at under 0.06 ppm/h in 1970, because the oxidant caused another form of environmental pollution—photochemical smog.

The development of stack gas desulphurization techniques was unfortunately very expensive for large fuel consumers—especially thermal power plants—to embark on. For example, the desulphurization of a thermal plant's emission required considerable amount of energy, corresponding to about 5% of its electrical generating capacity. Therefore, the stack gas desulphurization facilities of power plants did not immediately come into operation. Chubu-denryoku started to put its facilities into operation in 1973, and Denpatsu did so in 1975[56]. In the extreme case, Tokyo-denryoku confined its facilities to experimental use, not to operations.

Even worse, in the 1970s, the development of stack gas denitrification techniques was still in the research phase, and lengthening chimneys were also subject to a serious technical restraint[57]. Thus, the development of stack gas purification techniques stagnated, while the regulation of air pollution became stricter under Taiki-osen-bōshi-hō.

Use of low-sulphur fossil fuels

To deal with the strict regulation on SOx emission, given the poor technical potential of stack gas purification, fossil fuel consumers started to use several clean energy resources that were imported from all over the world[58]. First, starting in the mid 1960s, power plants in Tokyo, Chubu, Kansai and Chugoku-denryoku put into operation the direct combustion of crude oil. The oil

---

the top of the chimney, and it is 594 times more than that on the ground. It also equals the amount of the SOx emission divided by the square of the height of the chimney.

[56] Ikeda (1975), pp. 28-46; Tokyo-denryoku-kabushiki-gaisha-karyokubu (eds.) (1986), pp. 156-157; Chubu-denryoku-kabushiki-gaisha-karyokubu (eds.) (1988), pp. 250-252.

[57] Tanaka and Yamada (1971), p. 40-43; Tokyo-denryoku-kabushiki-gaisha-karyokubu (eds.) (1986), pp. 150-152; Chubu-denryoku-kabushiki-gaisha-karyokubu (eds.) (1988), pp. 250-254.

[58] For details, see Tokyo-denryoku-shashi-henshū-iinkai (eds.) (1983), pp. 628-638; Tokyo-denryoku-kabushiki-gaisha-karyokubu (eds.) (1986), pp. 152-156; Chubu-denryoku-kabushiki-gaisha-karyokubu (eds.) (1988), pp. 247-252; Shashi-henshū-shū-iinkai (eds.) (2001), pp. 495-497; Kansai-denryoku-gojūnen-shi-hensan-jimukyoku (eds.) (2002), pp. 358-360, 378-380 and 432-435.

refinery companies, whose business was to refine crude oil into gas oil or petrol, strongly objected to this action in terms of resource conservation. However, the electric power companies continued to burn crude oil because its sulphur content was slightly lower than that of Middle Eastern heavy oil.

Second, the import of heavy oil with ultra-low sulphur content from the Southeast Asian region began. For example, the sulphur content of Indonesian crude oil (Sumatra Light Crude and Lirik Crude Oil) or Bruneian crude oil (Light Seria Crude) was between 0.09% and 0.1% only. After being refined into heavy oil, their sulphur content was between 0.2% and 0.3%. Therefore, after 1966, the electric power companies replaced Middle Eastern heavy oil with Southeast Asian oil. In the case of Kansai-denryoku, the consumption of Sumatra Light Crude as a percentage of the total consumption of heavy oil increased from 12.1% in 1966 to 46.2% in 1970.

Third, in 1970, Tokyo-denryoku succeeded in operating the world's first liquefied natural gas-fired (LNG) power plant. Smoke and SOx emissions from the combustion of LNG were near zero, and NOx emission was also very low. Later, Tokyo-denryoku, Kansai and Chubu-denryoku also put their LNG-fired power plants into operation.

Finally, a few electric power plants used naphtha as part of their fuel, because its sulphur content was about 0.05%. However, it was not in common use due to its supply constraints.

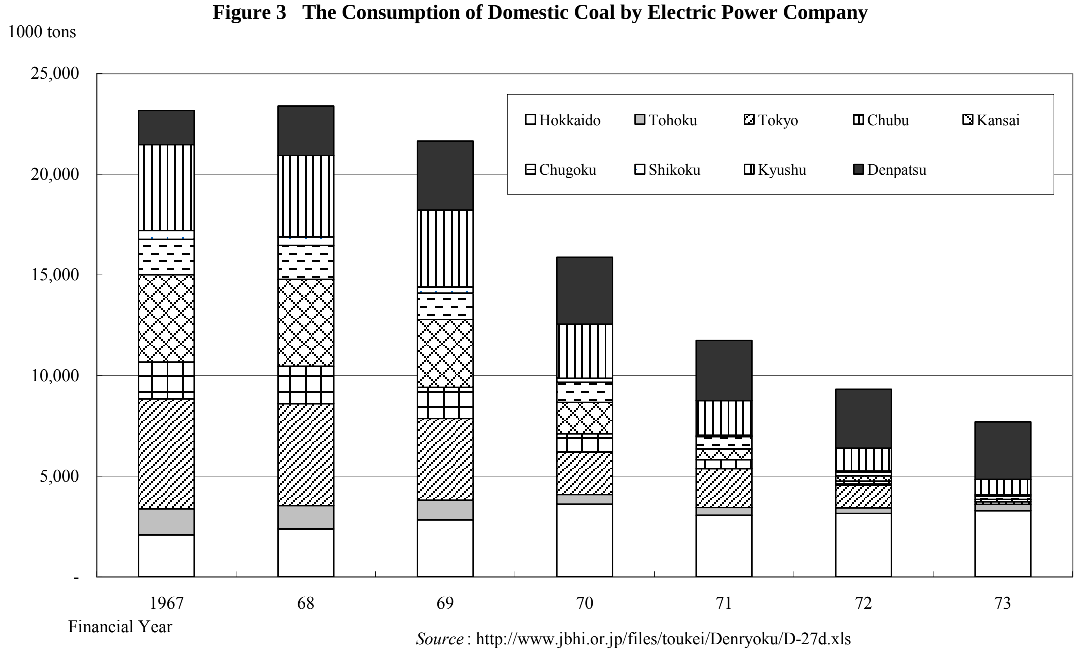
Owing to the use of these low-sulphur fossil fuels and the desulphurization of Middle Eastern heavy oil by the oil refinery companies after the mid 1970s[59], the annual average SOx concentration was 0.02 ppm in 1975[60]. Thus, the problem of SOx emission was moving gradually toward a solution, although that of NOx emission remained serious.

As the supply of these low-sulphur fossil fuels increased, the demand for domestic coal decreased. In particular, electric power plants' demand for domestic coal decreased rapidly. As **Figure 3** shows, almost all the electric power companies had virtually abandoned the use of domestic coal by the end of the 1960s, except Hokkaido-denryoku[61] [Hokkaido Electric Power Company], which put a new coal-fired power plant into operation in 1969, and Denpatsu, which was a special government corporation[62]. Neither inferior-quality coal with a high sulphur content

---

[59] Tsūshō-sangyō-shō-kōgai-hoan-kyoku (1970), pp. 155-156.
[60] Sangyō-kankyō-kanri-kyōkai (eds.) (2002), p. 98.
[61] Hokkaido-denryoku is located in Hokkaido.
[62] Hokkaido-denryoku-gojūnen-shi-hensan-iinkai (eds.) (2001), pp. 119-121.

Figure 3 The Consumption of Domestic Coal by Electric Power Company



Source : http://www.jbhi.or.jp/files/toukei/Denryoku/D-27d.xls
Note : Denpatsu is a special government corporation, and the others are private companies.

nor high-quality coal with a low sulphur content was able to compete with these ultra-low sulphur fossil fuels.

Rapid decrease in the supply of domestic coal

After 1968, as the demand for domestic coal decreased, the supply of domestic coal also decreased (see **Figure 2**). What then made it impossible for the collieries either to reduce the sulphur content of domestic coal by more repeated coal washing, or to exploit new markets for domestic coal other than fuel?

Let us start with the first part of the question[63]. It was very difficult for collieries to reduce the sulphur content of this high-quality coal by re-washing, because this caused an increase in production costs and a decrease in the organic efficiency. As the price of domestic high-quality coal became higher than that of heavy oil, collieries were forced to cut their production costs rather than to reduce the sulphur content of their coal. According to a trial calculation at Miike Colliery, about 2.5 million tons of coking coal was made by washing raw coal up to a sulphur content of about 1.4%, while 3.6 million tons of coking coal was made by washing raw coal up to 1.8%. Repeated coal washing also caused an increase in high-sulphur debris.

[63] For details, see Shimanishi (2004), pp. 11-15.

However, under the strict regulation of SOx emission, there was no demand for inferior-quality coal mixed with high-sulphur debris. Moreover, it was impossible to reduce the sulphur molecules that combined with other molecules inside the coal by washing[64].

Let us now consider the second part of the question[65]. First, there was an active demand for coking coal during the period of rapid economic growth. It was an attractive market for domestic coal, but steelmakers—the largest consumers of coking coal—preferred coal with high caking properties over coal without caking properties, which the electric power plants preferred. Therefore, it was difficult for collieries to ship their coal to electric power plants as coking coal. In addition, the steelmakers also preferred high-quality coal with a low sulphur content, because the sulphur content worsened the quality of the pig iron. Although Tsushō-sangyō-shō [the Ministry of International Trade and Industry] and several coal mining companies attempted to develop techniques for using coal without caking properties as coking coal, they were not able to put them to commercial use due to the cost, objections by steelmakers and so on[66].

Second, after 1964, there was an attempt to produce artificial light-weight aggregate (ALA) for construction using debris and inferior-quality coal[67]. However, this also caused SOx emission, because ALA was made by calciting debris and inferior-quality coal with a high sulphur content [68]. The Nihon-keiryou-kotsuzai Company was jointly established in 1966 by Santan-chiiki-shinkō-jigyōdan [the Development of Coal Mining Areas Corporation], Mitsubishi-semento [Mitsubishi Cement Company], Nittetsu-kogyō [Nittetsu Mining Company] and so on to produce ALA; however, it was dissolved in 1975 because its operations were unprofitable, which were caused by investing in a stack gas desulphurizer between 1973 and 1974[69].

Many coal mining companies thus lost their markets and were forced to close their pits, even those with abundant reserves. On the other hand, a few major companies such as Mitsui were able to survive this management difficulty by specializing in shipping a little high-quality coal or coking coal, both of which were, however, much lower in the organic efficiency due to repeated

[64] Sasaki (1995), p. 205.
[65] For details, see Shimanishi (2008).
[66] Taiheiyō-tankō-kabushiki-gaisha (1969).
[67] Santan-chiiki-shinkō-jigyōdan (1964).
[68] Ibid.
[69] Nittesu-kogyō-kabushiki-gaisha (eds.) (1979), pp. 208-210.

coal washing. Therefore, the management situations of these survivors worsened seriously enough to continue operations on their own.

Conclusion

'The energy revolution' that began in the early 1950s brought about the following industrial and environmental changes. First, a wide range of industries began to switch fuel from coal to heavy oil, because heavy oil imported from the Middle East was more efficient, in terms of price and heat control, than high-quality domestic coal. Second, the conversion of fuel did not necessarily reduce the consumption of domestic coal. Coal mining companies increased the organic efficiency of coal, and successfully commodified inferior-quality coal, such as raw coal and low-calorie coal, which had been thrown away in the past. Several electric power companies preferred such inferior-quality coal to heavy oil because of its lower price. Finally, the combustion of those fossil fuels with a high sulphur content, that is, both heavy oil and inferior-quality domestic coal, caused serious air pollution by SOx.

In 1968, when the government started to regulate SOx emission by Taiki-osen-bōshi-hō, the electric power companies rapidly replaced Middle East heavy oil and domestic coal by fossil fuels with a low sulphur content, such as crude oil, heavy oil from Southeast Asia, LNG and naphtha. Despite the relatively low sulphur content and high organic efficiency of domestic coal, its use under the new law required electric power companies to develop stack gas desulphurization techniques that were very expensive to embark on. Coal mining companies were thus forced either to close their pits, even those with abundant reserves, or to specialize in shipping high-quality coal, which was, however, lower in the organic efficiency due to repeated coal washing.

The increase in the organic efficiency of coal during 'the energy revolution' suggests that economic growth between 1955 and 1968 was not characterized solely by the wasteful use of fossil fuels. However, the environment was severely damaged. Japan's economic growth after 1968 seems to have followed a more environment-friendly path by substituting domestic coal for low-sulphur fossil fuels imported from all over the world. Although this mitigated air pollution to some extent, it also led to a rapid decrease in the organic efficiency of coal. Moreover, the Japanese economy became more dependent on foreign energy resources.

Kobori argues that Japan's economic growth after the inter-war period was an energy-saving economy in terms of energy efficiency[70], whereas the findings here suggest that it changed from a resource-saving economy between 1955 and 1968 to a resource-consuming economy after 1968 in terms of the organic efficiency and the degree of dependence on foreign resources. The findings here also show that in an economy dependent on fossil energy resources, unlike an economy dependent on biomass energy resources, the efficient and rational use of fossil energy resources does not always contribute to environment-friendly economic growth.

[70] Kobori (2006), pp. 65-67. See also Sughihara (2008).

Appendix

Coalfields and Industrial Districts in Japan

Note: The name of a coalfield is underlined, and that of an industrial district is boxed.

References

Abe Yanosuke, 'Teihinitan-katsuyō ni tsuite' [Utilization of Low Grade Coals], in Kōgyō-gijutsu-in [The Agency of Industrial Science and Technology] (eds.), *Sekitan-riyō-gijutu-kaigi-kaigiroku (IV)* (Tokyo: Nihon-dōryoku-kyōkai-enerugī-taisaku-honbu), pp. 124-129.

Chubu-denryoku-kabushiki-gaisha-karyokubu [The Thermal Power Dept. of Chubu Electric Power Company] (eds.) (1988), *Chubu-denryoku-karyoku-hatsuden-shi* (Aichi: Chubu-denryoku-kabushiki-gaisha-karyokubu).

Enerugī-keizai-kenkyūsho [The Institute of Energy Economics, Japan] (eds.) (1986), *Sengo-enerugī-sangyō-shi* (Tokyo: Toyo-keizai-shinpo-sha).

Fukuoka-tsūshō-sangyō-kyoku [The Fukuoka Bureau of International Trade and Industry] (eds.) (1965), I*izuka-hokubu-nōgata-nanbu-chiiki-shidō-hōkokusho (Chikuho-hen 1)* (Fukuoka: Fukuoka-tsūshō-sangyō-kyoku).

Hokkaido-denryoku-gojūnen-shi-hensan-iinkai [The Editorial Board of Fifty years' History of Hokkaido Electric Power Company] (eds.) (2001), *Kita no akari wo tomoshi-tuzukete—hokkaido-denryoku-gojūnen no ayumi—*(Hokkaido: Hokkaido-denryoku-kabushiki-gaisha).

Horiuchi Toshitaka (1933), 'Suisen-tan no haibun ni tsuite', *Nenryo-kyokai-shi* [*The journal of the fuel society of Japan*], vol. 12, no. 129, pp. 742-752.

Iijima Nobuko (2000), *Kankyō-mondai no Shakai-shi* (Tokyo: Yuhikaku).

Ikeda Souroku (1975), 'Sekitan-karyoku-hatsudensho no haien-datsuryū-sōchi ni tsuite', *Dengen-kaihatsu-kabushiki-gaisha-chōsa-shiryōo*, no. 55, pp. 28-46.

Joban-kyodo-karyoku-50-nenshi-hensan-iinkai [The Editorial Board of Fifty Years' History of Joban Joint Power Company] (eds.) (2005), *50-nen no ayumi 1955-2005—hito to jigyō no kiroku*—(Tokyo: Joban-kyodo-karyoku-kabushiki-gaisha).

Kamioka Namiko (1987), *Nihon no Kōgai-shi* (Tokyo: Sekai-shoin).

Kanda Sayako (2007), 'Enerugī to kankyō: kankyō-keizaishi no furontia', in Keio University the 21st Century COE Program (eds.), *Enerugī to kankyō: kankyō-keizaishi no furontia* (Tokyo: Keio University the 21st Century COE Program).

Kankyō-chō [The Environment Agency] (1969), *Kōgai-hakusho* (Tokyo: Ōkura-shō-insatsu-kyoku).

Kansai-denryoku-gojūnen-shi-hensan-jimukyoku [The Editorial Office of Fifty Years' History of Kansai Electric Power Company] (eds.) (2002), *Kansai-denryoku-gojūnen-shi* (Osaka: Kansai-denryoku-kabushiki-gaisha).

Kawana Hideyuki (1985), 'Kōgai-mondai no yonjūnen-shi', *Kankyō-jōhō-kagaku* [*Environmental information science*], vol. 14, no. 1, pp. 8-14.

Kobori Satoru (2005), '1950-nendai no enerugī-seisaku—jūyu-syōhi-kisei wo chūshin ni—' [Japan's energy policy during the 1950s], *Shakai-Keizaishi-gaku* [*Socio-economic history*], vol. 70, no. 6, pp. 47-69.

Kobori Satoru (2006), 'Senji-ki/sengo-fukkō-ki-nihon no netsukanri-undō/netsu-kanri-seisaku' [The Japanese heat control movement and heat control policies in war and reconstruction periods], *Osaka-daigaku-keizaigaku* [*Osaka economic papers*], vol. 56, no. 2, pp. 40-68.

Kobori Satoru (2007), 'Senkanki-nihon ni okeru enerugī-setsuyaku-seisaku no tenkai', [Japanese energy-saving policy during the interwar era], *Rekishi to keizai* [*The journal of political economy and economic history*], vol. 49, no. 3, pp. 48-64.

Konishi Masaharu (1990), '(6) Miike-sentan- kōjō no hensen', *Shigen/Sozai-gakkai-shi* [*Journal of the Mining and Materials Processing Institute of Japan*], vol. 106, no. 11, pp. 15-17.

Kyushu-denryoku-kabushiki-gaisha [Kyushu Electric Power Company] (eds.) (1982), *Kyushu-denryoku-sanjūnen-shi* (Fukuoka: Kyushu-denryoku-kabushiki-gaisha).

Kyushu-keizai-chōsa-kyōkai [The Kyushu Economic Research] (1961), 'Tankō-gōrika no gendankaiteki-tokushitsu', *Kyushu-keizai-chōsa-kyōkai-chōsa-hōkoku*, no. 89.

Mitsumata Gaku, Morimoto Sanae and Murota Takeshi (eds.), *Comonzu-kenkyū no furontia—sanya-kaisen no kyōteki-sekai*—(Tokyo: Tokyo-daigaku-shuppan-kai).

Mori Sukeyuki (1998), 'Nihon ni okeru sentan-gijutsu no hensen to sonogo no tenkai' [A History and the Development of Coal Preparation in Japan], *Shigen-shori-gijutsu* [*Resources processing*], vol. 45, no. 2, pp. 74-86.

Murota Takeshi (2006), 'Jevons no hōsoku', in Kankyo-keizai/seisaku-gakkai [Society for Environmental Economics and Policy Studies] (eds.) *Kankyō-keizai/seisaku-gaku no kiso-chishiki* (Tokyo: Yuhikaku), pp. 330-331.

Murota Takeshi and Mitsumata Gaku (2004), *Iriai-rinya to comonzu—jizoku-kanou na kyōyū no mori*—(Tokyo: Nihon-Hyoronsha).

Mamiya Yosuke (2002), ‘Kankyō-shigen to comonzu’, in Sawa Takamitsu et al. (eds.), *Kankyō no keizai-riron* (Tokyo: Iwanami-shoten).

Mitsui-kōzan-kabushiki-gaisha [Mitsui Mining Company], ‘Miike-tan wa henbō-su’, in Mitsui-kōzan-kabushiki-gaisha (eds.), *Shanai-Jihō*, no. 84, p. 20.

Mitsui-kōzan-kabushiki-gaisha [Mitsui Mining Company] (eds.) (1990), *Otoko-tachi no seiki—mitsui-kozan no hyakunen*—(Tokyo: Mitsui-kōzan-kabushiki-gaisha).

Nezu Tomoyoshi (1958), *Sekitan-kokka-tōseishi* (Tokyo: Nihon-keizai-kenkyūsho).

Nihon-tekkō-renmei-sengo-tekkō-shi-hensan-iinkai [The Editorial Board of the Postwar History of the Japan Iron and Steel Federation] (eds.) (1959), *Sengo-tekkō-shi* (Tokyo: Nihon-tekkō-renmei).

Nittesu-kogyō-kabushiki-gaisha [Nittesu Mining Company] (eds.), *yonjūnen-shi* (Tokyo: Nittesu-kogyō-kabushiki-gaisha).

Oda Yasunori (1987), *Toshi-kōgai no keisei—kindai-osaka no seichō to seikatsu-kankyō* (Kyoto: Sekai-shisō-sha).

Okada Yuko (1999), ‘Kosaka-kōzan-engai-mondai to hantai-undō—1901–17 nen—’ [The Movement against Smoke Pollution in Kosaka Copper Mine: 1901-1917], *Shakai-Keizaishi-gaku* [*Socio-economic history*], vol. 56, no. 3, pp. 59-88.

Ousaka Susumu (1989), ‘(2) Ashibetsu-sentan-kōjō no hensen’, *Shigen/Sozai-gakkai-shi* [*Journal of the Mining and Materials Processing Institute of Japan*], vol. 105, no. 11, pp. 5-7.

Saito Toshio (1960), ‘Denryoku-yō-tan to shite no teihini-tan to sono kaishū-hōhō’ [Low Grade Coal for Electric Power and its Recovery Process] in Kōgyō-gijutsu-in [The Agency of Industrial Science and Technology] (eds.), *Sekitan-riyō-gijutu-kaigi-kaigiroku (III)* (Tokyo: Nihon-dōryoku-kyōkai-enerugī-taisaku-honbu), pp. 144-152.

Sangyō-kankyō-kanri-kyōkai [The Japan Environmental Management Association for Industry] (eds.) (2002), *20 seiki no nihon-kankyō-shi* (Tokyo: Sangyō-kankyō-kanri-kyōkai).

Sanjūnen-shi-hensan-iinkai [The Editorial Board of Thirty Years’ History] (eds.) (1984), *Denpatsu-sanjūnen-shi* (Tokyo: Dengen-kaihatsu-kabushiki-gaisha).

Santan-chiiki-shinkō-jigyōdan [The Development of Coal Mining Areas Corporation] (1964), *Bota-yama-miriyō-shigen no kaihatsu-chōsa-hōkokusho* (unpublished).

Sasaki Takashi (1995), *Ryūtai-kakumei to nittan no taiō* (private edition).

Sekitan-kōgai-jigyōdan [The Coal Mine Damage Corporation] (eds.) (1971), *Sekitan-kōgai-fukkyu-shi* (Fukuoka: Hōman-sha).

Sekitan-seisaku-shi-hensan-iinnkai [The Editorial Board of the History of Coal Policy] (eds.) (2002a), *Sekitan-seisaku-shi* (Tokyo: Sekitan-enerugī-sentā).

Sekitan-seisaku-shi-hensan-iinnkai [The Editorial Board of the History of Coal Policy] (eds.) (2002b), *Sekitan-seisaku-shi (shiryō-hen)* (Tokyo: Sekitan-enerugī-sentā).

Sekitan-tsūshin-sha [Sekitan Press Company] (eds.) (1962), *Sekitan-nenkan* (Fukuoka: Sekitan-tsūshin-sha).

Shashi-henshū-shō-iinkai [The Sub Editorial Board of Fifty Years' History of Chugoku Electric Power Company] (eds.) (2001), *Chugoku-denryoku 50-nen-shi* (Hiroshima: Chugoku-denryoku-kabushiki-gaisha).

Shimanishi Tomoki (2004), 'Sengo-sekitan-shijō to sekitan-sangyō—enerugī-kakumei-ki ni okeru mitsui-kōzan no jirei wo chushin ni—' [A Historical Study on Coal Market, 1950-1975: A case study on Mitsui Mining Company], *KUMQRP Discussion Paper Series*, DP2004-008.

Shimanishi Tomoki (2005), 'Sengo-sekitan-sangyō-gōrika-shoki ni okeru oote-tankō no gōrika to sokōken-tankō' [Major coalmining companies during the early period of post-war rationalization: the Hokkaido Colliery and Steamship Company Ltd. and the sub-leasing of coalmines from the early 1950s to the early 1960s], *Shakai-Keizaishi-gaku* [*Socio-economic history*], vol. 70, no. 6, pp. 25-46.

Shimanishi Tomoki (2008), 'Suitai-sangyō ni okeru kigyō-kōdō—sengo-sekitan-sangyō no saihen to sono kiketsu—' [The Business Behavior in the Declining Industry: A case study on coalmining industry in postwar Japan], unpublished PhD thesis, Keio University.

Sugihara Kaoru (2008), 'Kaseki-shigen-sekai-keizai no keisei to kōzō—enerugī-kōritsu no kaizen to kankyō-hakai no 200-nen—' in http://www.humanosphere.cseas.kyoto-u.ac.jp (The 11th G-COE Seminar for paradigm formulation).

Taiheiyō-tankō-kabushiki-gaisha [Taiheiyo coalmining company] (1969), *Shin-sekitan-seisaku to tōsha* (unpublished).

Tanaka Kusuyata and Yamada Takeshi (1971), 'Haien no datsuryū to chisso-sankabutsu no yokusei (taiki-osen narabi ni dōryoku-puranto to kōogai' [Removal of Sulfur Oxides from Flue Gas and Control of Nitrogen Oxides (Air Pollution as well as Power Plant and Pollution)], *Nihon-kikai-gakkai-shi* [*Journal of the Japan Society of Mechanical Engineers*], vol. 74, no. 3, pp. 35-44.

Tokyo-denryoku-kabushiki-gaisha-karyokubu [The Thermal Power Dept. of Tokyo Electric Power Company] (eds.) (1986), *Tokyo-denryoku-karyoku-gijutsu-shi* (Tokyo: Tokyo-denryoku-kabushiki-gaisha-karyokubu).

Tokyo-denryoku-shashi-henshū-iinkai [The Editorial Board of the History of Tokyo Electric Power Company] (eds.) (1983), *Tokyo-denryoku-sanjūnen-shi* (Tokyo: Tokyo-denryoku-kabushiki-gaisha).

Tsūshō-sangyō-shō-daijin-kanbō-chōsa-tōkei-bu [The Research and Statistics Department of the Minister's Secretariat of the Ministry of International Trade and Industry] (eds.) (1960), *Zenkoku-tankō-yōran* (Fukuoka: Sekitan-tsūshin-sha).

Tsūshō-sangyō-shō-daijin-kanbō-sōgō-enerugī-seisaku-ka [The General Energy Policy Division of the Minister's Secretariat of the Ministry of International Trade and Industry] (eds.) (1966-1973), *Sōgō-enerugī-tōkei* (Tokyo: Tsūshō-sangyō-kenkyū-sha).

Tsūshō-sangyō-shō-kōgai-hoan-kyoku, [The Pollution Security Bureau of the Ministry of International Trade and Industry] (1970), *Sangyō to kōgai—shinban—* (Tokyo, Tsūsan-shiryō-chōsa-kai).

Tsūshō-sangyō-shō-sekitan-kyoku [The Coalmining Bureau of the Ministry of International Trade and Industry] (eds.) (1953), *Kōtanka-mondai to Gōrika no hōkō* (Tokyo: Sekitan-keizai-kenkyusho).

Ui Jun (eds.) (1975), *Gijutsu to sangyō-kōgai* (Tokyo: United Nations University).

Yada Toshifumi (1975), *Sengo-nihon no sekitan-sangyō* (Tokyo: Shinhyoron).