Chapter 5
Low-Carbon Society in 2050

5.1 Low Carbon Power Supply Systems in 2050

5.1.1 Means to Achieve Low Carbonization

At COP 21, Japan set a long-term goal of reducing CO_2 emissions by 80% of 2013 levels by 2050. As we have seen in Chap. 4, we will try to reduce carbon from a range of angles, but in order to achieve the high target of 80% reduction, we must also optimize the configuration of the power supply used for power generation.

The following methods can be considered to significantly reduce CO_2 emissions from the power supply sector:

1. Decrease the amount of power generation.
2. Increase power generation efficiency.
3. Increase the ratio of power generation by natural gas fuel, which has low CO_2 emissions per calorific value.
4. Add CCS to fossil fuel power generation.
5. Increase the proportion of power generation by renewable energy.
6. Increase the proportion of nuclear power generation.

Let's look at these in order. With regard to the amount of electricity generated (1), measures such as switching to highly efficient electric appliances has progressed after the Great East Japan Earthquake, and it has already declined by about 10%. The annual power generation amount is within 1000 TWh, and this trend will continue in the future. If the annual rate drops by 1%, the consumption of electricity will be about 650 TWh per year in 2050, 30% lower than the current rate. For the direct use of heat and components of fossil fuels (e.g., automobiles and hot water supply), replacement with electricity will continue in order to save energy, so the demand will increase, but we believe that annual amount of electricity generated will not exceed 800 TWh.

H. Komiyama, K. Yamada, *New Vision 2050*, Science for Sustainable Societies,
https://doi.org/10.1007/978-4-431-56623-6_5

Table 5.1 Electricity generation cost (Yen/kWh) and CO_2 emissions (g-CO_2/kWh)

	2013		2030		2050	
	Cost	CO_2	Cost	CO_2	Cost	CO_2
Nuclear power	8.8	20	8.8	20	8.8	20
Hydroelectric power	10.8	11	10.8	11	10.8	11
Coal	7.7	943	7.8	881	7.8	881
LNG	10.8	473	11.4	430	11.8	430
Oil	16.7	738	17.9	738	18.9	738
Solar power	16.0	38	9.5	15	5.7	15
Wind power	14.1	25	10.2	25	10.2	25
Geothermal power	12.5	15	12.5	15	8.0	15
Biomass	33.6	5	10.9	5	10.9	5

Source: Created based on materials from the Center for Low Carbon Society Strategy, Japan Science and Technology Agency

With regard to power generation efficiency (2), solar power generation that will be used in large quantities in the future is expected to have an efficiency of 30%, which is 1.5 times the present value. Even with natural gas power generation, under combined power generation in which fuel cells work together from the same heat source, the power generation efficiency may be nearly 70%, or more than 1.2 times the present value. Regarding (3), natural gas has a low CO_2 emission level of about 50% that of coal, and there is room to increase its usage. However, in a society in which reduction of CO_2 emissions by 80% will be achieved, natural gas will not become the main power source. With regard to CCS in (4), there are difficulties in the uptake of the technology such as economic restrictions and restrictions on site conditions, but there is a possibility that it will be carried out in the future, and it is worth considering. In terms of nuclear power (6), the situation is such that it will not become the main power supply under the current circumstances of low public support.

Considering the above, renewable energy (5), which is expressly stated in Vision 2050, is the option that seems most promising in the future. In the next section, we will discuss the establishment of a power supply sector incorporating a large amount of renewable energy.

5.1.2 80% Reduction and Power Generation Costs

Table 5.1 lists power generation costs and CO_2 emissions per kWh that will become widespread in 2050. To generate the values of renewable energy in 2050, we used the cost of the state of technology in 2030 mentioned in Chap. 4, taking into account the speed of its dissemination. With regard to power supply in 2050, solar power generation and wind power generation will be introduced in large quantities. Since the amount of power generated in the case of both solar and wind power changes

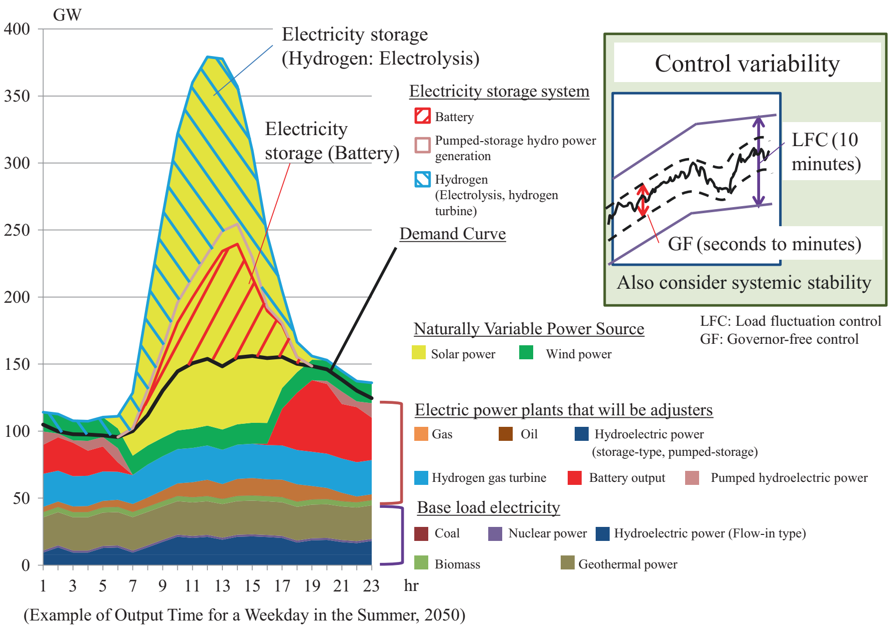

Fig. 5.1 Summertime power supply and demand storage model. (Source: Created based on materials from the Center for Low Carbon Society Strategy, Japan Science and Technology Agency)

depending on the weather, a power storage system is necessary to achieve a balance between power supply and demand.

Figure 5.1 shows an example of the balance between power supply and demand, focusing on summer weekdays when there are large fluctuations. To achieve balance between power supply and demand in the order of 10 min, introducing a storage battery should suffice. However, taking into account frequency control in the order of several tens of milliseconds as well as response to emergency blackouts, we need a power supply that consists of 50% that uses a rotating machine such as a turbine (New Energy and Industrial Technology Development Organization, “NEDO Renewable Energy Technology White Paper: Issues That Should Be Overcome and Solutions Toward Expanding Dissemination of Renewable Energy, 2nd Edition,” 2014, pp. 635 Morikita Publishing Co., Ltd.). Although there is a possibility that it may become 50% or less due to power grid design and development of a new control system, here I have decided to focus on power supplies in which a rotary power generation system accounts for 50% or more.

Stable power sources capable of rotating power generation are mainly thermal power, hydropower, nuclear power, geothermal power, and biomass power generation. Among these, geothermal power generation is a method that generally utilizes the heat of a geothermal reservoir located at a relatively shallow depth underground, but attention is focused on utilization of high temperature rocks deep underground due to concerns about effects on hot spring areas. Hot dry rock (HDR) geothermal power generation (also known as the enhanced geothermal system) is also effective in reducing electricity costs, and development is also progressing in the U.S. It is not so complex system, but more investigation and research on deep underground structure are necessary to develop the technology for practical application. In Japan, it would be possible to complete a power generation system of 100 TWh (13 GW) per year by 2050.

Given that the status of use of nuclear power generation is not foreseeable in 2050, there is considerable uncertainty in the role of nuclear and geothermal power among the stable power sources by 2050. Therefore, we have changed the annual total power generation amount to 600–1200 TWh, and we also examined how much nuclear and geothermal power generation would be required if the amount of electricity generated was reduced. We would also like to think about minimization of costs when a reduction of 80% of CO_2 emissions is achieved. The unit power generation costs for nuclear power and HDR geothermal power generation and CO_2 emissions are almost equal. As a result, however the proportion of power supply from the two power sources changes, the effect on total power cost can still be seen by using the value of the sum of the amount of power generated by these two sources.

5.1.3 Consideration of the Best Power Supply Configuration

Table 5.2 shows the comparison of power generation costs calculated by changing the annual power generation amount, power supply configuration, and CO_2 reduction rate. As mentioned in the previous section, since power consumption is estimated to be 650 TWh per year by 2050, the annual demand for electricity has been set with 700 TWh as the reference value in Table 5.2, considering that this is a highly feasible numerical value. In addition, we calculated the cost of power generation by setting various patterns from 600 TWh, which is slightly less than the reference value, to 1200 TWh, which is higher than the reference value.

Cases 1, 2, and 4 are examples in which the annual demand for electricity has been set between 600 and 1000 TWh, and the amount of CO_2 emissions has been reduced by 80%. In these cases, nuclear power generation and HDR geothermal power generation are not included, but if the demand is less than 800 TWh, the cost would be about ¥11/kWh in all cases. If the demand falls slightly below the current level, it is possible to reduce the electricity cost below the current level of ¥12/kWh even without nuclear power and HDR thermal power generation.

In contrast, if the demand reaches 1000 TWh as in Case 5, the cost rises sharply to ¥18/kWh. Even power savings of about 20% will be effective in reducing cost and the amount of CO_2 emissions under such a scenario.

In Case 3, the demand for power is the same as in Case 2, but the target for reducing CO_2 emissions has been increased to 90%. The power cost at this point is high at ¥16/kWh.

Table 5.2 Cost by power supply configuration and percentage of CO_2 reduction in 2050

Case		1	2	3	4	5	6	7
Demand for electricity (TWh)		600	700	700	800	1,000	1,000	1,200
Annually generated electricity (TWh)	Nuclear power	0	0	0	0	0	0	0
	Hydroelectric power	130	130	130	130	130	130	130
	Coal	100	28	0	0	0	14	0
	LNG	19	166	97	224	211	190	330
	Solar power	373	398	544	494	746	500	746
	Wind power	8	8	7	9	38	24	124
	Geothermal power	12	12	12	12	12	12	12
	Geothermal power (hot dry rock)	0	0	0	0	0	200	0
	Biomass	30	31	31	31	31	22	31
	Total	672	772	822	900	1,169	1,092	1,373
Battery capacity (GWh)		423	466	666	631	780	621	795
Amount of hydrogen use (TWh)		0	0	53	0	118	0	119
Cost of generating electricity (Yen/kWh)		10.8	10.8	16.1	11.0	18.4	9.9	17.3
Annual CO_2 (Mt-CO_2)		113	113	57	113	113	113	170
Rate of CO_2 reduction (Cf. 2013)		80%	80%	90%	80%	80%	80%	70%

Source: Created based on materials from the Center for Low Carbon Society Strategy, Japan Science and Technology Agency

In Case 6, the demand for power and CO_2 emission reduction target are the same as in Case 5, but the HDR geothermal power generation of 200 TWh is included. By increasing stable renewable energy, cheap coal-fired power can be used and storage battery capacity is decreased compared to Case 5, so the power generation cost is the cheapest.

Also, as shown in Case 7, if the demand for power is as high as 1200 TWh, the power generation cost will substantially increase, even if the CO_2 reduction rate is reduced to 70%.

It should be noted that the value of total power generation is higher than the demand for power because it is calculated so that the cost is minimal. In order to set surplus power generation to 0, storage batteries and hydrogen power generation are used together, but they are high cost, so it is cheaper to discard the surplus. Even if solar power and wind power generation used to produce hydrogen cost ¥0, electrolysis equipment and transportation incur expenses. In Cases 3, 5, and 7, the power generation costs are high, but hydrogen power generation is included as stable power supply in all cases.

From the above, it has been clarified that if the power supply configuration is as presented in Cases 1, 2, and 4, the target of reducing CO_2 emissions by 80% in 2050 can be achieved without increasing the power generation cost and without introducing nuclear power and HDR geothermal power generation.

5.2 Reducing Carbon in Major Fields

5.2.1 Value-Added Industry and Low Carbon

What approach should we take to create a bright low carbon society (a platinum society) using low-carbon power that achieved a reduction in CO_2 emissions by 80%? Let us consider using the data for 2013, which is the base year for CO_2 emissions in Japan in COP 21.

Since CO_2 emissions in 2050 will be reduced by 80%, this represents a mass of 250 million tons (deducting 1003 million tons from 1254 million tons). If the annual economic growth rate is assumed to be 0.4%, the nominal GDP value is estimated to be ¥600 trillion, which is about ¥80 trillion more than it is now. In terms of CO_2 emissions per ¥1 trillion of GDP, the amount of CO_2 emissions must be drastically reduced from the current 2.4 million tons to 420,000 tons.

Table 5.3 illustrates the amount of CO_2 emissions, added value, and CO_2 emissions per ¥1 trillion of value-added for each industry sector in 2013. The power sector emits a large amount of CO_2, accounting for 45% of the total emissions (567 million tons), but since most of the emissions are allocated to each industry sector, they are not represented in this figure. However, as shown in the previous section, it is possible to reduce emissions from the power sector by 80% (454 million tons).

In the demand sector, households emit 224 million tons of CO_2, which is equivalent to 18% of the total. By saving energy in the household and with a new power supply configuration, we estimate that CO_2 can be reduced by 179 million tons (of which power usage accounts for 129 million tons), which is equivalent to 80% of CO_2 emissions in this sector. The transportation sector can also reduce 196 million tons of CO_2 (of which power usage accounts for 8 million tons) which is also 80% of CO_2 emissions. In total, a reduction of 375 million tons can be achieved.

Therefore, the amount of CO_2 emissions to be reduced in other industrial sectors, excluding emissions due to power usage (where reduction by 317 million tons is possible), CO_2 emissions could be reduced by a total of 311 million tons.

5.2.2 The Ideal State of the Steel Industry

The steel sector emits the largest amount of CO_2 in the industrial sector. As mentioned in Chap. 2, 40–70 billion tons of new steel is needed globally in the future. Some of the required new steel could possibly be manufactured in Japan even in 2050, considering the high quality of Japanese steel products and high-level of energy saving technology. Production of steel for export will increase CO_2 emissions, but it will be difficult for steel consuming countries to bear this burden. Thus, when we consider reductions in CO_2 emissions by 80% in 2050, it is necessary to consider the increase in CO_2 emissions due to exports.

Table 5.3 Volume of CO_2 emissions by industrial sector (2013)

Industries and households	Total CO_2 emissions (Millions of tons)	Amount of value-added (Trillions of yen)	Volume of CO_2 emissions per one billion worth of value-added
Agriculture, forestry, and fishery industries	4.2	6.45	654
Mining industry, etc.	2.5	0.35	7,164
Construction	12.3	31.48	390
Food and drinks manufacturing industry	21.1	15.39	1,369
Textile industry	12.2	2.26	5,396
Wood products, furniture, and other industries	2.6	0.70	3,658
Pulp, paper, and paper products manufacturing	23.7	2.37	10,013
Printing and related industries	2.8	2.68	1,048
Chemical industry	82.0	8.00	10,248
Petroleum products and coal products manufacturing industries	3.0	4.37	683
Plastic, rubber, and leather products manufacturing industries	10.0	1.46	6,850
Cement, sheet glass, and limestone manufacturing industries	45.7	3.10	14,765
Iron and steel industry	199.8	5.95	33,578
Non-ferrous metal manufacturing industry	8.0	1.60	5,004
Metal products manufacturing	7.3	5.46	1,333
General machinery and devices manufacturing industries	2.3	11.23	205
Production machinery and devices manufacturing industries	4.0	2.85	1,411
Industrial machinery and devices manufacturing industries	4.0	1.51	2,675
Electric circuits for electric parts and devices manufacturing industries	10.4	5.60	1,865
Telecommunications machinery and devices manufacturing industries	2.3	1.28	1,818
Transportation machinery and devices manufacturing industries	14.8	13.00	1,140
Machine manufacturing and other products	4.0	1.93	2,082

(continued)

Table 5.3 (continued)

Industries and households	Total CO_2 emissions (Millions of tons)	Amount of value-added (Trillions of yen)	Volume of CO_2 emissions per one billion worth of value-added
Other manufacturing industries	1.5	5.26	292
Electricity, gas, heat, and water supply industries	10.6	9.12	1,167
Telecommunications industry	20.6	28.83	716
Transportation and postal industries (excluding privately owned vehicles)	259.2	26.55	9,760
Wholesale and retail industries	63.3	70.97	893
Finance and insurance industries	2.5	23.48	107
Real estate and rental industries	18.5	66.35	279
Academic research, specialized, and technology services	5.6	0.28	20,263
Hospitality and food services	48.8	14.08	3,470
Life-related services and entertainment industries	33.1	13.59	2,439
Education and learning assistance industry	17.8	0.68	26,121
Medicine and welfare	29.1	36.79	790
Multiple-services industries	0.6	27.06	23
Other service industries	35.0	11.20	3,126
Official duties	4.5	59.83	76
Households	224.1	0	–
Total	1,254	523	2,400

Source: Created based on materials from the Center for Low Carbon Society Strategy, Japan Science and Technology Agency

Since the amount of CO_2 emissions from the steel sector in 2013 was 200 million tons per year, the amount of emissions will be 40 million tons for the same level of production if we achieve an 80% reduction in 2050. Among the current CO_2 emissions, the amount of emissions attributed to power generation is 51 million tons, which can be reduced by 80% if we use future low carbon power supplies. The issue is how to reduce other emissions from within the steel production process.

Table 5.4 is an illustration of the steel production in 2050 when such a significant reduction is achieved. There are two major methods of steel production: the Blast Furnace Method using iron ore as a raw material and the Electric Furnace Method using iron scrap as a raw material. Table 5.4 displays simulated images of the steel industry in 2013 and 2050. The supply and demand of steel by each manufacturing method, and the amount of CO_2 emitted in correlation with steel supply are presented in the figure. The situation in 2050 is based on the following five assumptions.

Table 5.4 Present and future demand for iron and steel, examples of CO_2 emissions

		2013 (190 million ton (Mt) of CO_2 emissions)	2050 (40 million ton of CO_2 at 80% reduction)	
			Case 1	Case 2
		Iron and steel (CO_2 emissions, Mt)	Iron and steel (CO_2 emissions, Mt)	Iron and steel (CO_2 emissions, Mt)
Supply		121 (200)	80 (64)	67 (40)
Details	Blast furnace method	86 (185)	30 (54)	17 (30)
	Electric furnace method	25 (15)	50 (10)	50 (10)
	Import	10	0	0
Demand		121	80	67
Details	Domestic	58	40	37
	Exported steels, etc.	42	20	10
	Exported products	21	20	20

Source: Created based on materials from the Center for Low Carbon Society Strategy, Japan Science and Technology Agency

1. Use of future electric power that reduces CO_2 emissions by 80%.
2. Because of the increase in recycled steel, the production volume of the Electric Furnace Method will be double the current volume.
3. The Electric Furnace Method will achieve energy saving by 20%.
4. The production rate by the Blast Furnace Method will be significantly reduced.
5. Steel export volume will be significantly reduced.

Based on the above, we calculated two case examples. It should be noted that the steel produced by the current Electric Furnace Method cannot be used for certain products such as thin automobile plates and large-diameter pipes. Currently, development is underway to produce iron and steel materials with properties suitable for such purposes.

In Case 1, total supply is assumed to be 80 million tons, which is a reduction of 30% from the current level, on the premise that domestic demand will decrease and export of steel materials will be narrowed down to high value-added products in the future. In addition, steel production by the Electric Furnace Method is assumed to be doubled to 50 million tons in 2050. The Electric Furnace Method has an energy conservation rate of 20%. In this case, the total CO_2 emissions are 64 million tons, which fall short of the target of 80% reduction from 2013 levels.

In Case 2, export volume of steel from the demand side is further lowered. The steel production by the Blast Furnace Method was 17 million tons, making the total production 67 million tons. This will result in CO_2 emissions of 40 million tons, achieving an 80% reduction from 2013 levels.

In order to achieve an 80% reduction under the conditions of Case 1, the CO_2 emissions must be further reduced by 24 million tons. To this end, it is conceivable to combine the Blast Furnace Method with CCS. Assuming that CCS cost will be ¥4000 per ton of CO_2, the annual cost will be about ¥96 billion, and the cost increase per ton of steel will be about ¥3200, if the cost increase is allocated to the whole Blast Furnace Method. It may be possible to manufacture high value-added steel corresponding to this cost increase.

Therefore, a more realistic scenario is Case 2, where the Electric Furnace Method using recycled steel is doubled and steel production using the Blast Furnace Method is reduced by approximately 80%. If we can change the structure of steel production in this way, reduction of CO_2 emissions by 80% is possible. In this case, the level of unit CO_2 emissions using the Blast Furnace Method is assumed to be the same as the current level. If improvements to the manufacturing process continue, it will be possible to increase the production quantity of steel using the Blast Furnace Method commensurate with that progress.

5.3 Reducing CO_2 Emissions by 80% Across Japan

5.3.1 Low Carbonization by Sector in 2050

Reducing CO_2 emissions by 80% in the three sectors (households, transportation, and steel) is not easy; however, it is feasible. These emissions account for 53% of Japan's total emissions, and thus CO_2 emissions from other sectors must also be reduced by 80%.

Table 5.5 illustrates the CO_2 emissions by sector in the base year 2013 and in 2050, by which CO_2 emissions are to be reduced by 80%. Out of the total emissions in other sectors (586 million tons of CO_2/year), 60% is derived from electricity, so this can be reduced by 80% in the future as previously discussed. The focus is the remaining 40%, involving reduction of emissions due to the use of fossil fuels from 235 million tons to 47 million tons. This can be realized with energy saving and an increase in electricity usage ratio. While expanding economic activities, it is

Table 5.5 CO_2 emissions of the 3 sectors (households, iron and steel, and transportation) for 2013 and for 2050 when 80% reduction will have been realized

		CO_2 emissions (Mt)		
		Electricity	Other than electricity	Total
The 3 sectors	2013	216	452	668
	2050	43	90	133
Other sectors	2013	351	235	586
	2050	70	47	117
Total	2013	567	687	1,254
	2050	113	137	250

Source: Created based on materials from the Center for Low Carbon Society Strategy, Japan Science and Technology Agency necessary to promote low-carbon technologies or systems and to accelerate changes in the industrial structure through innovation.

Tables 5.6a, 5.6b, and 5.6c presents an overall perspective of the situation. Let's consider Japan's CO_2 emissions and value-added by industry sector in 2013 based on each of these plots.

Table 5.6a Amount of value-added and percentage by sector (2013)

Order	Industry, etc.	Amount of value-added (Trillions of yen)	Percentage (%)	Volume of CO_2 emissions (kt)	Percentage (%)	Volume of CO_2 emissions per one billion yen worth of value-added (t)
1	Wholesale and retail industries	70.97	13.6%	63,346	5.1%	893
2	Real estate and rental industry	66.35	12.7%	18,513	1.5%	279
3	Official duties	59.83	11.4%	4,546	0.4%	76
4	Medical and welfare	36.79	7.0%	29,060	2.3%	790
5	Construction	31.48	6.0%	12,264	1.0%	390
6	Telecommunications industry	28.83	5.5%	20,629	1.6%	716
7	Multiple-services business	27.06	5.2%	626	0.0%	23
8	Transportation and postal industries + Transportation fuels	26.55	5.1%	259,183	20.7%	9,760
9	Finance and insurance industries	23.48	4.5%	2,507	0.2%	107
10	Food and drinks manufacturing industries	15.39	2.9%	21,076	1.7%	1,369
11	Hospitality and food service industries	14.08	2.7%	48,847	3.9%	3,470
12	Life-related services and entertainment industries	13.59	2.6%	33,145	2.6%	2,439
13	Transportation machinery and devices manufacturing industries	13.00	2.5%	14,823	1.2%	1,140
14	General machinery and devices manufacturing industries	11.23	2.1%	2,299	0.2%	205
15	Other service industries	11.20	2.1%	35,030	2.8%	3,126

(continued)

Table 5.6a (continued)

Order	Industry, etc.	Amount of value-added (Trillions of yen)	Percentage (%)	Volume of CO_2 emissions (kt)	Percentage (%)	Volume of CO_2 emissions per one billion yen worth of value-added (t)
16	Electricity, gas, heat, and water supply industries	9.12	1.7%	10,640	0.8%	1,167
17	Chemical industry	8.00	1.5%	82,018	6.5%	10,248
18	Agriculture, forestry, and fishery industries	6.45	1.2%	4,219	0.3%	654
19	Iron and steel industry	5.95	1.1%	199,814	15.9%	33,578
20	Electric circuits for electric parts and devices manufacturing industries	5.60	1.1%	10,448	0.8%	1,865
21	Metal products manufacturing industries	5.46	1.0%	7,280	0.6%	1,333
22	Other manufacturing industries	5.26	1.0%	1,535	0.1%	292
23	Petroleum products and coal products manufacturing industries	4.37	0.8%	2,982	0.2%	683
24	Cement, sheet glass, and limestone manufacturing industries	3.10	0.6%	45,741	3.6%	14,765
25	Production machinery and devices manufacturing industries	2.85	0.5%	4,026	0.3%	1,411
26	Printing and related industries	2.68	0.5%	2,805	0.2%	1,048
27	Pulp, paper, and paper products manufacturing industry	2.37	0.5%	23,718	1.9%	10,013
28	Textile industry	2.26	0.4%	12,185	1.0%	5,396
29	Machine manufacturing and other products	1.93	0.4%	4,014	0.3%	2,082
30	Non-ferrous metal manufacturing industry	1.60	0.3%	8,016	0.6%	5,004

(continued)

Table 5.6a (continued)

Order	Industry, etc.	Amount of value-added (Trillions of yen)	Percentage (%)	Volume of CO_2 emissions (kt)	Percentage (%)	Volume of CO_2 emissions per one billion yen worth of value-added (t)
31	Industrial machinery and devices manufacturing industry	1.51	0.3%	4,035	0.3%	2,675
32	Plastic, rubber, and leather products manufacturing industries	1.46	0.3%	10,000	0.8%	6,850
33	Telecommunications machinery and devices manufacturing industry	1.28	0.2%	2,319	0.2%	1,818
34	Wood products, furniture, and other industries	0.70	0.1%	2,563	0.2%	3,658
35	Education and learning assistance industry	0.68	0.1%	17,772	1.4%	26,121
36	Mining industry, etc.	0.35	0.1%	2,489	0.2%	7,164
37	Academic research, specialized, and technology services	0.28	0.1%	5,591	0.4%	20,263
38	Households (all energies)			224,098	17.9%	
	Total	523.08		1,254,201	100.0%	2,398

Table 5.6a shows value-added by industry sector and their shares. Total value-added of the top five industries accounts for 51% of the GDP, but the total CO_2 emissions from these industries is merely 10% of the total. In contrast, Table 5.6b, where industries are sorted in descending order of CO_2 emissions, the sum of emissions from the top five industries account for 52% of the total, but the sum of value-added is merely 24% of the GDP. Furthermore, according to Table 5.6c, where industries are sorted by CO_2 emissions per ¥1 trillion of value-added, the sum of industries between 26th and 37th from the lowest value-added accounts for 71% of the GDP. However, the sum of CO_2 emissions remains at only 13% of the total.

Just because an industry's value-added is large, it does not mean that the amount of CO_2 emitted is necessarily large, or vice versa. Needless to say, the most desirable combination is large value-added with small CO_2 emissions. Building on this, the major issues to be addressed are as follows:

Table 5.6b Volume of CO_2 emissions by sector (2013)

Order	Industry, etc.	Volume of CO_2 emissions (kt)	Percentage (%)	Amount of value-added (Trillions of yen)	Percentage (%)	Volume of CO_2 emissions per 1 billion yen worth of value-added (Tons)
1	Transportation and postal industries + Transportation fuels	259,183	20.7%	26.55	5.1%	9,760
2	Iron and steel industry	199,814	15.9%	5.95	1.1%	33,578
3	Chemical industry	82,018	6.5%	8.00	1.5%	10,248
4	Wholesale and retail industries	63,346	5.1%	70.97	13.6%	893
5	Hospitality and food service industries	48,847	3.9%	14.08	2.7%	3,470
6	Cement, sheet glass, and limestone manufacturing industries	45,741	3.6%	3.10	0.6%	14,765
7	Other service industries	35,030	2.8%	11.20	2.1%	3,126
8	Life-related services and entertainment industry	33,145	2.6%	13.59	2.6%	2,439
9	Medical and welfare	29,060	2.3%	36.79	7.0%	790
10	Pulp, paper, and paper products manufacturing industries	23,718	1.9%	2.37	0.5%	10,013
11	Food and drinks manufacturing industry	21,076	1.7%	15.39	2.9%	1,369
12	Telecommunications industry	20,629	1.6%	28.83	5.5%	716
13	Real estate and rental industries	18,513	1.5%	66.35	12.7%	279
14	Education and learning assistance industry	17,772	1.4%	0.68	0.1%	26,121
15	Transportation machinery and devices manufacturing industry	14,823	1.2%	13.00	2.5%	1,140
16	Construction	12,264	1.0%	31.48	6.0%	390
17	Textile industry	12,185	1.0%	2.26	0.4%	5,396
18	Electricity, gas, heat, and water supply industries	10,640	0.8%	9.12	1.7%	1,167

(continued)

Table 5.6b (continued)

Order	Industry, etc.	Volume of CO_2 emissions (kt)	Percentage (%)	Amount of value-added (Trillions of yen)	Percentage (%)	Volume of CO_2 emissions per 1 billion yen worth of value-added (Tons)
19	Electric circuits for electric parts and devices manufacturing projects	10,448	0.8%	5.60	1.1%	1,865
20	Plastic, rubber, and leather products manufacturing	10,000	0.8%	1.46	0.3%	6,850
21	Non-ferrous metal manufacturing	8,016	0.6%	1.60	0.3%	5,004
22	Metal products manufacturing industry	7,280	0.6%	5.46	1.0%	1,333
23	Academic research, specialized, and technology services industry	5,591	0.4%	0.28	0.1%	20,263
24	Official duties	4,546	0.4%	59.83	11.4%	76
25	Agriculture, forestry, and fishery industries	4,219	0.3%	6.45	1.2%	654
26	Industrial machinery and devices manufacturing industry	4,035	0.3%	1.51	0.3%	2,675
27	Production machinery and devices manufacturing industry	4,026	0.3%	2.85	0.5%	1,411
28	Machine manufacturing and other products	4,014	0.3%	1.93	0.4%	2,082
29	Petroleum products and coal products manufacturing	2,982	0.2%	4.37	0.8%	683
30	Printing and related industries	2,805	0.2%	2.68	0.5%	1,048
31	Wood products, furniture, and other industries	2,563	0.2%	0.70	0.1%	3,658
32	Finance and insurance industries	2,507	0.2%	23.48	4.5%	107
33	Mining industry, etc.	2,489	0.2%	0.35	0.1%	7,164

(continued)

Table 5.6b (continued)

Order	Industry, etc.	Volume of CO_2 emissions (kt)	Percentage (%)	Amount of value-added (Trillions of yen)	Percentage (%)	Volume of CO_2 emissions per 1 billion yen worth of value-added (Tons)
34	Telecommunications machinery and devices manufacturing industries	2,319	0.2%	1.28	0.2%	1,818
35	General machinery and devices manufacturing industry	2,299	0.2%	11.23	2.1%	205
36	Other manufacturing industries	1,535	0.1%	5.26	1.0%	292
37	Multiple-services business	626	0.0%	27.06	5.2%	23
38	Households (all energies)	224,098	17.9%			
	Total	1,254,201	100.0%	523.08		2,398

1. Structural change of industries to services with low CO_2 emissions per value-added and further reduction of CO_2 emissions.
2. As exemplified in the high-emission steel industry, the intra-industry system change is required centered on recycled products.
3. Promotion of energy conservation in all industrial fields.
4. Introduction of low carbon power supply systems through establishment of a large amount of renewable energy production.
5. Creation of new low-carbon industries.
6. Development of new functional materials supporting the above changes.

5.3.2 *Value-Added by Industry and CO_2 Emissions in 2050*

As we have seen so far, reducing 80% of CO_2 emission by 2050 in the power sector as well as the other three sectors (household, steel, and transport), which together account for 81% of total CO_2 emissions, is now within reach. If we can reduce the remaining 19% of the total CO_2 emissions by 80%, we can achieve an overall reduction of 80% in 2050. Since we can see this much improvement at this stage, we have also applied the same numbers to related industries. The remaining amount is small, so we decided on an emission reduction of roughly 50 to 90% (on average 80%) considering the situation of each industry.

Quantitatively forecasting the value-added and industrial structure of each industrial sector in 2050 is more difficult than projecting the CO_2 emissions. In this esti-

Table 5.6c Sector-specific volume of CO_2 emission per value-added (2013)

Order	Industry, etc.	Volume of CO_2 emissions per 1 billion yen worth of value-added (Tons)	Amount of value-added (Trillions of yen)	Percentage (%)	Volume of CO_2 emissions (kt)	Percentage (%)
1	Iron and steel industry	33,578	5.95	1.1%	199,814	15.9%
2	Education and learning assistance industry	26,121	0.68	0.1%	17,772	1.4%
3	Academic research, specialization, and technology services	20,263	0.28	0.1%	5,591	0.4%
4	Cement, sheet glass, and limestone manufacturing industries	14,765	3.10	0.6%	45,741	3.6%
5	Chemical industry	10,248	8.00	1.5%	82,018	6.5%
6	Pulp, paper, and paper products manufacturing industries	10,013	2.37	0.5%	23,718	1.9%
7	Transportation and postal industries + transportation fuels	9,760	26.55	5.1%	259,183	20.7%
8	Mining industry, etc.	7,164	0.35	0.1%	2,489	0.2%
9	Plastic, rubber, and leather products manufacturing industries	6,850	1.46	0.3%	10,000	0.8%
10	Textile industry	5,396	2.26	0.4%	12,185	1.0%
11	Non-ferrous metal manufacturing industries	5,004	1.60	0.3%	8,016	0.6%
12	Wood products, furniture, and other industries	3,658	0.70	0.1%	2,563	0.2%
13	Hospitality and food service industries	3,470	14.08	2.7%	48,847	3.9%
14	Other service industries	3,126	11.20	2.1%	35,030	2.8%
15	Industrial machinery and devices manufacturing	2,675	1.51	0.3%	4,035	0.3%
16	Life-related services and entertainment industry	2,439	13.59	2.6%	33,145	2.6%

(continued)

Table 5.6c (continued)

Order	Industry, etc.	Volume of CO_2 emissions per 1 billion yen worth of value-added (Tons)	Amount of value-added (Trillions of yen)	Percentage (%)	Volume of CO_2 emissions (kt)	Percentage (%)
17	Machine manufacturing and other products	2,082	1.93	0.4%	4,014	0.3%
18	Electric circuits for electric parts and devices manufacturing industry	1,865	5.60	1.1%	10,448	0.8%
19	Telecommunications machinery and devices manufacturing industry	1,818	1.28	0.2%	2,319	0.2%
20	Production machinery and devices manufacturing industry	1,411	2.85	0.5%	4,026	0.3%
21	Food and drinks manufacturing industry	1,369	15.39	2.9%	21,076	1.7%
22	Metal products manufacturing industry	1,333	5.46	1.0%	7,280	0.6%
23	Electricity, gas, heat, and water supply industries	1,167	9.12	1.7%	10,640	0.8%
24	Transportation machinery and devices manufacturing industry	1,140	13.00	2.5%	14,823	1.2%
25	Printing and related industries	1,048	2.68	0.5%	2,805	0.2%
26	Wholesale and retail industries	893	70.97	13.6%	63,346	5.1%
27	Medical and welfare	790	36.79	7.0%	29,060	2.3%
28	Telecommunications industry	716	28.83	5.5%	20,629	1.6%
29	Petroleum products and coal products manufacturing	683	4.37	0.8%	2,982	0.2%
30	Agriculture, forestry, and fishery industries	654	6.45	1.2%	4,219	0.3%
31	Construction industry	390	31.48	6.0%	12,264	1.0%
32	Other manufacturing industries	292	5.26	1.0%	1,535	0.1%
33	Real estate and rental industry	279	66.35	12.7%	18,513	1.5%

(continued)

Table 5.6c (continued)

Order	Industry, etc.	Volume of CO_2 emissions per 1 billion yen worth of value-added (Tons)	Amount of value-added (Trillions of yen)	Percentage (%)	Volume of CO_2 emissions (kt)	Percentage (%)
34	General machinery and devices manufacturing industry	205	11.23	2.1%	2,299	0.2%
35	Finance and insurance industries	107	23.48	4.5%	2,507	0.2%
36	Official duties	76	59.83	11.4%	4,546	0.4%
37	Multiple-services business	23	27.06	5.2%	626	0.0%
38	Households (all energies)				224,098	17.9%
	Total	2,398	523.08		1,254,201	100.0%

Source: Created based on materials from the Center for Low Carbon Society Strategy, Japan Science and Technology Agency

mation, we assumed the GDP as value-added in 2050 to be ¥600 trillion, and then distributed it after considering the situation of each industry.

The estimation is based on the following premises. On the supply side, labor productivity is improved due to advances in technologies such as AI, sensors, robots, and computers, as well as sophistication of systems that make use of them. In addition, development of low-carbon, high-performance products and new processes through the development of new materials will proceed, and production of new materials, parts, and structural materials will also expand. However, new needs will be created on the demand side. Although there may be changes within service industries such as information and communications, medicine and welfare, accommodation and catering, education, wholesale and retail, and finance and insurance, their size will expand as a whole.

Overall, technological innovation for low carbonization will progress, and a change in industrial structure accompanying expansion of economic activity will occur. Table 5.7 shows the current state (2013) and the future image (2050) of industries that are expected to grow and expand in the future. Value-added will increase from ¥190 trillion to ¥262 trillion in seven industries, mainly in the services industry, such as information and telecommunications, medical care and welfare, and accommodation and catering, while CO_2 emissions will decrease from 200 million tons to 55 million tons. These industries cover most of their energy with electricity, and it is possible to further decrease CO_2 emissions by development of energy saving of electric drive equipment. Therefore, it can be said that it is easier to promote low carbonization in these industries compared with the manufacturing industry.

Table 5.7 Examples of industries that can expand by 2050

		Value-added (trillion Yen)		CO_2 emissions (G t)		CO_2 Emissions (t) per billion Yen of value-added	
		2013	2050	2013	2050	2013	2050
1	Information and Communication	29	50	21	10	720	200
2	Medicine and Welfare	37	52	29	8	790	150
3	Hospitality and Food Services	14	25	49	12	3,500	480
4	Wholesale and Retail	71	80	63	7	890	90
5	Financial and Insurance	24	30	2.5	0.3	110	9
6	Life Related, Services, and Entertainment	14	20	33	10	2,400	500
7	Education and Research Technology Services, etc.	1	5	23	8	23,000	1,600
Total		190	262	221	55	(Average: 1,160)	(Average: 210)

Source: Created based on materials from the Center for Low Carbon Society Strategy, Japan Science and Technology Agency

In Japan, which will have realized a reduction of 80% of CO_2 emissions by 2050, the total CO_2 emissions would be 250 million tons and the GDP ¥600 trillion. The CO_2 emissions per ¥1 billion value-added (hereinafter referred to as "CO_2 emissions per value-added") is expected to be 420 tons, which is a significant reduction from the current 2400 tons.

Table 5.7 shows the average emission of industries per value-added, which is calculated to decrease from current 1160 to 210 tons.

Let's look at each of these industries individually. Although the value-added of "information and communication" is estimated to be 1.7 times larger than current level, this simulation is based on a conservative assumption where the annual average growth rate is 1.5%, so there is a possibility of further expansion.

Similarly, under the "medical care and welfare" category, given the recent progress in medical equipment, medical technology, treatment modalities, and the amount of wealth possessed by the elderly people, the number of people willing to pay extra for receiving treatment is expected to increase. If we have a comfortable hospital environment in combination with high medical technology in Japan, the demand from overseas will also increase, which could double the current value-added. If Japan's state-of-the-art medical system is constantly adopted and flexible management becomes possible, this value will be further increased.

In the medical field, the percentage of electricity use is large, so even the low carbonization of electricity alone will lead to a considerably large low carbon industry, and it is still essential to achieve high insulation in hospital buildings and further low carbonization of various medical equipment. The amount of power required by the heavy particle radiotherapy equipment used for cancer treatment is as high as 3000 kW with one unit. The electricity cost accounts for a considerable part of the total treatment cost (¥3 million per person), and the amount of CO_2 emissions is large, yet in principle, it is possible to save a substantial amount of electricity. For low carbonization of not only heavy particle radiotherapy equipment but also for the medical and welfare sector to be achieved, it is important to develop a system using various high functional materials. This is also a suitable field to leverage Japan's strengths.

By incorporating the themes discussed above into concrete issues and working to solve each issue, it is possible to achieve both targets of economic expansion and low carbonization. Given the accelerated changes in future society, we consider that enhancing the "education and research technology services" sector is a particularly important approach. To be able to respond to the ever-changing society, it is necessary to have an educational system that allows everyone to acquire new knowledge and ways of thinking and continue learning. Such a system will inevitably grow as an industry. Furthermore, the expansion of research service sectors such as society and engineering or science to drive this social change and to discover the seeds such as new technologies and systems for a new society will similarly advance. There is a possibility that the value-added in these sectors may grow beyond the scope of these estimations.

5.3.3 Image of CO_2 Emissions and Changes in GDP in all Industries

Lastly, let us consider low carbonization of all industries. The CO_2 emissions data per value-added in 2013 and 2050 are interspersed, and Fig. 1.13 is graphically presented once again (Fig. 5.2). The vertical axis shows CO_2 emissions per unit value-added, while the horizontal axis shows value-added.

In Table 5.6a, 5.6b and 5.6c, the CO_2 emissions of households that do not produce value-added are ranked number 38 of domestic sector. Fig. 5.2 is provided to demonstrate the relationship between value-added of the industrial sector and CO_2 emissions, by allocating the total CO_2 emissions of the household sector into 62.8 million tons to the petroleum and coal product manufacturing industry, and into 161.3 million tons to the electricity, gas, and water supply industry.

This is how Fig. 5.2 should be interpreted. In the case of 2013, the value-added (GDP) on the horizontal axis is the highest at ¥523 trillion, and the lowest plot on the vertical axis where CO_2 emissions per unit value-added is 23,000 tons/¥1 trillion is the services industry. In Table 5.6c, it is ranked at 37th, the lowest plot. If ¥27 trillion of value-added of the services industry is deducted, the remaining GDP is ¥496 trillion. The plot at ¥496 trillion on the horizontal axis and at 76,000 tons/¥1 trillion on the vertical axis in Fig. 5.2 is the public sector.

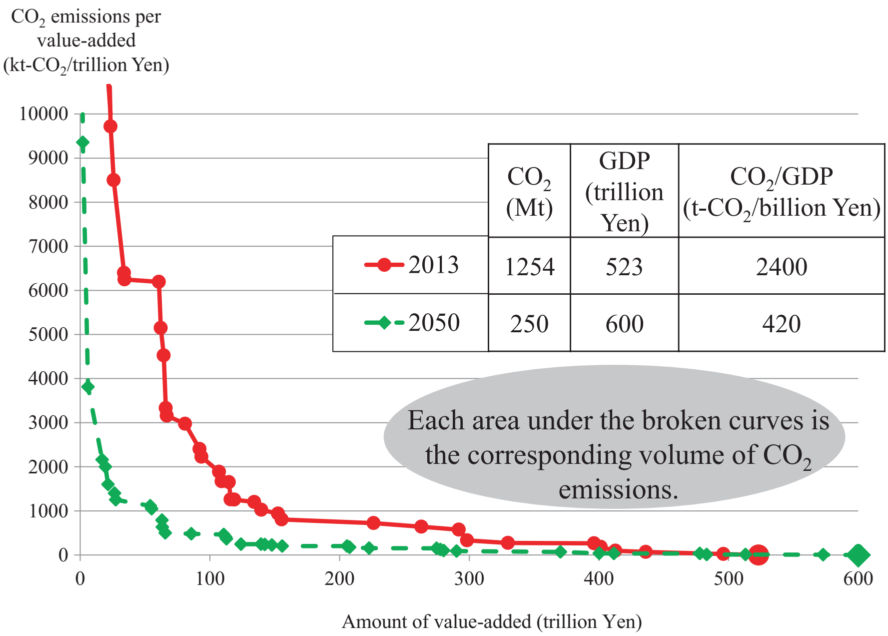

Fig. 5.2 CO_2 emissions and value-added by industry. (Source: Created based on materials from the Center for Low Carbon Society Strategy, Japan Science and Technology Agency)

Since the area inside the line connecting the plots indicates the total CO_2 emissions, low carbonization means minimizing this area. Therefore, to create a bright low carbon society, it is important to increase the value-added while lowering the CO_2 emissions per value-added.