CLIMATE AND ENVIRONMENT

Promotion of Constructing Zero Carbon Society: Effectiveness of Quantitative Evaluation of Technology and System for Sustainable Economic Development

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Abstract

When setting construction of euphoric and satisfying zero-carbon society as a goal, we should consider the back-casting scenario of how to reach it. To that end, it is necessary to use a simple but clear indicator of GDP and CO_2 emissions without separating, economic development and decarbonization. To achieve the target below 2 degrees, technology development and diffusion (TD&D) play key role. This paper clarifies the usefulness and importance of quantitative technical evaluation that can be used for investment judgment and expansion of TD&D which practically accelerate to low carbonization and innovation in world.

Challenge

Globally common and inevitable goal for us is aiming at building a zero carbon society. It is important to consider the back-casting scenario of how to achieve it. In order to realize the zero carbon society, quantitative evaluation is indispensable.

First of all, we must respond to the questions whether targeted society is reachable from the viewpoint of economic development, and secondly, whether society can reach the goal with fewer barriers. The answer to the former can be thought of as a simple yet clear indicator of GDP and CO_2 emissions. For the latter, the development and the widespread diffusion of technology are the most effective measures with less barriers. In that context, appropriate quantitative assessment of technology has an important role in investment decisions in technology development and use.

- By adequately monitoring the scale and timing of introducing the optimal low-carbon technology system will maximize lower-cost and lower-carbon opportunities.
- Usually future cost of technology in estimation models is often derived from numerical values calculated from 'black box'. In order to make effective investment decisions, it is necessary to clarify whose basis and boundary conditions of the calculation.
- Investment opportunities are fully utilized by implementing the technology installation plan with considering development level of the country and/or region.
- To introduce low-carbon technology, it is important to clarify the spillover effects on economic, energy and environmental aspects in a whole society. It reduces the risk of being marginalized due to difficulties such as inflexible and short-term investment decisions.

Proposal

Proposal 1: To achieve the global warming target of 2 degrees or less, it is important to raise the decreasing rate of CO_2 emissions per GDP. To that end, it is necessary to accelerate the technology transfer speed and to introduce appropriate technology systems through international cooperation.

Rationale

- Figure 1 shows the change in world CO_2 emissions per GDP from 1850 to the present. From the Industrial Revolution to the beginning of the 1900s period, the increase due to expansion of industries with high CO_2 emissions was remarkable. After the peak of 0.93 t /1000USD in 1913, there was a decrease due to changes in the industrial structure and the spread of new technologies. In the past 100 years, the average rate of reduction is 0.0047 / year, in the past 50 years it was 0.0074 / year.

- Future temperature can be estimated by using this CO_2/GDP, relation of ΔT and accumulated CO_2 (Matthews, 2009), and economic growth rate (Figure 2). If the rate of decrease slows down (0.0030 /yr.), The temperature rise will be 4.3 degrees in 2100, while continuing with the current reduction rate (0.0074 /yr.), the goal below 2 degrees can be achieved by reducing the annual carbon emissions to zero by 2074.

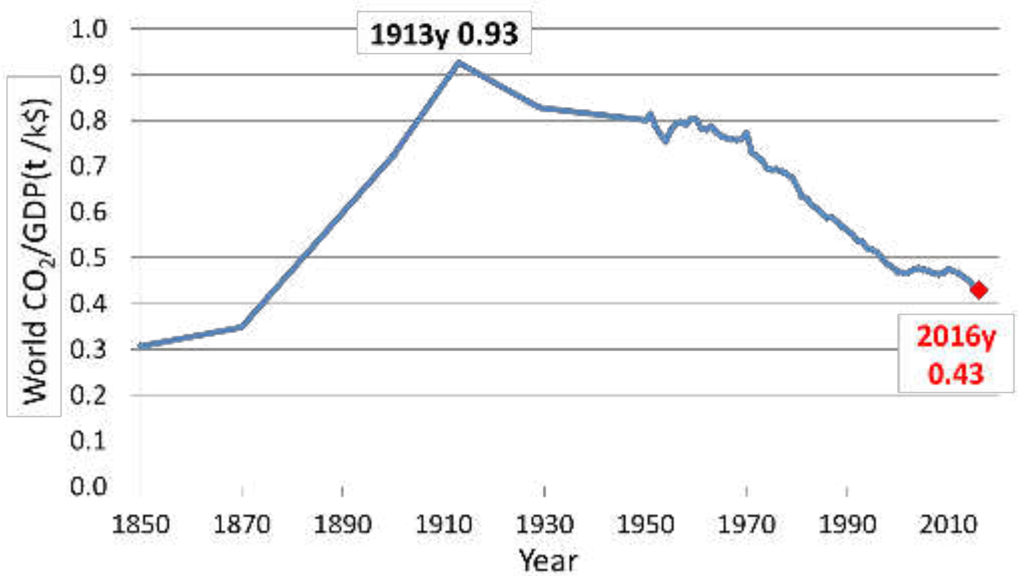
- Figure 3 shows the relationship between population and GDP growth rate of seven developed countries (upper two figures) and regions (lower). When the growth rate of the population is high, GDP growth rate tends to be high. In developed countries, the economic growth rate in recent years has declined. On the other hand, in developing countries the population growth rate has slowed somewhat, but the economic growth rate is high[1]. By innovation for decarbonization leading to these economic growth and introduction of new systems, we must induce leapfrogging of the development of developing countries. In these countries, infrastructure is not ready and should be newly installed. In other words, there will be

[1] The annual growth rate of population from 2015 to 2050 is expected to fall to less than 1% in most areas, but only Africa is still high, 2.2% (UN, 2017), and the GDP growth rate is also high at 4.4%. (EDMC, 2018).

advantage of being easy to introduce the state of art equipment/facility. Therefore, compared with developed countries, investment for decarbonizing society is more efficient, effects appear earlier.

Suggestions on means to implement

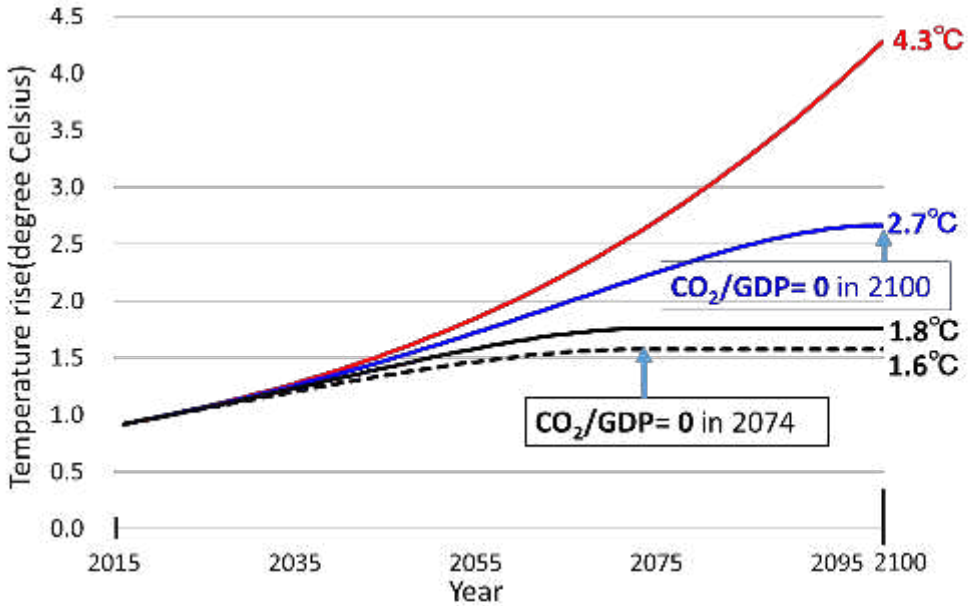
- By increasing the reduction rate of CO_2 emissions per GDP, it is possible to approach the goal of 2 degrees or less. To this end, mechanism and framework will be significant that raises GDP by reducing CO_2, e.g., technology development and deployment.
- As the population decreases, it is important how quickly to decrease GHG emissions, and it is necessary to look at both economy and environment. To that end, it is important to link technological progress and economy and accelerate technology transfer between countries/regions.



Growth rate(%)	1870-2015	1950-2015	1990-2000	2000-2007	2008-2015
World annual economy	2.7	3.6	3.0	3.4	2.2
Population	1.2	1.7	1.4	1.3	1.2

Figure 1. Historical change of CO_2 per GDP in the world.

Note: LCS calculated from several data source: 1971-2015: GDP, CO_2 from EDMC databank. Before 1970: GDP from Maddison (1995), CO_2 from Boden et al (2010). As GDP from 1971 to 2015 was based on 2010 and GDP prior to 1970 was based on 1990, so the two periods were consolidated at the ratio to 1971 and adjusted to 2010 base.
Source: Yamada, 2017 and 2019.



	Decrease rate of CO_2/GDP (/yr.)	Economic growth rate (%/yr.)	Temperature rise (degree C)
	0.0030	3	4.3
	0.0051	3	2.7
	0.0074	3	1.8
	0.0074	2	1.6

Figure 2. Effect of technology progress and economic growth on global warming.

Source: Yamada, 2019

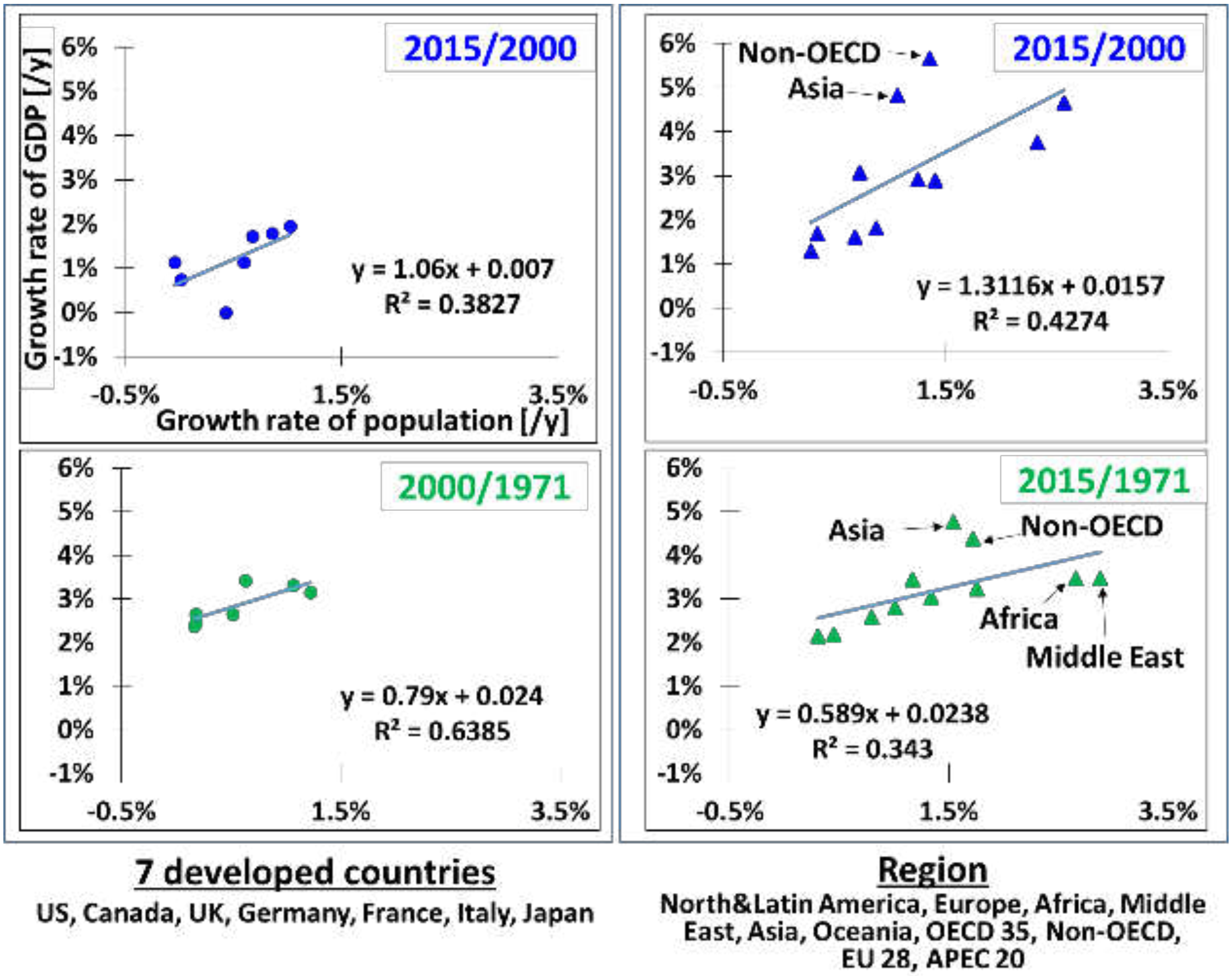


Figure 3. Relationship between annual growth rate of population and GDP.
(Left: 7 developed countries, Right: world regions)

Estimated by LCS.

Table 1. Relationship between annual growth rate of population and GDP

	GDP growth rate			Population growth rate		
	1971-2015	1971-2000	2000-2015	1971-2015	1971-2000	2000-2015
US	2.8%	3.3%	1.8%	1.0%	1.1%	0.9%
Canada	2.7%	3.1%	2.0%	1.2%	1.2%	1.0%
UK	2.2%	2.4%	1.7%	0.3%	0.2%	0.7%
Germany	1.9%	2.4%	1.1%	0.1%	0.2%	-0.04%
France	2.1%	2.6%	1.1%	0.5%	0.5%	0.6%
Italy	1.7%	2.6%	-0.002%	0.3%	0.2%	0.4%
Japan	2.5%	3.4%	0.8%	0.4%	0.6%	0.02%

Source: EDMC, 2018. Original source: World Development Indicators, World Bank.
Note: Used USD with exchange rate of 2010 average for GDP.

Proposal 2: It is essential to establish a scheme that quantitatively predicts future technological innovation and provides necessary information, such as timing and scale, of infrastructure investment for low-carbon society.

Rationale

- Capital investment is important for technology development and diffusion, and the evolution of technology innovation is decided depending on how to judge timing and scale of the investment. In particular, it is important to pay attention to those that do not penetrate the market sufficiently yet but need massive diffusion at an early stage in the future, such as low carbon technology. The data of CO_2 emissions, energy consumption, and environmental performance of new technology cannot be derived by simply extending information on the existing technologies and the technology-introduction effects to value-chain is unclear in such case. It is difficult to make investment decisions by learning curves. In LCS, quantitative technology evaluation method, ECCC (Engineering based CO_2 emission and Cost Clarification methodology) has been developed. This is a detailed study of the manufacturing process of technology from heat and material balance, building a database, and making it possible to calculate cost, energy consumption and CO_2 emissions for manufacturing of low carbon technology (Fig. 4). This clarifies the cost, CO_2 emissions and material kind and amount needed to introducing individual technologies into society as well as integrating various technologies in combination.

- Figure 5 shows the transition of the predicted cost value according to ECCC method (marker '○' in the figure) and the actual price ('×' in the figure) of the past solar cells. As of 1991, when the annual production of 10 MW to 100 GW for solar cell manufacturing system was evaluated, and the cost was about $ 4 per W, and it was calculated to become less than 1USD/W, by future technology,. In fact, the current price is almost the same as the previously estimated price. According to latest LCS forecasts based on technology assessment, it will be less than 40 cents in 2030. . Thus, the quantitative technology evaluation by ECCC method, can predict the technology cost before the technology penetrates in the real world, and can provide important information (timing, size) for capital investment judgment.

- Table 2 shows the estimation of the power generation cost in the case at different technological levels using the ECCC method for various low carbon technologies in Japan (LCS, 2017). As the technical level rises, the power generation cost decreases. For example, in the case of a 80% reduction in CO_2 emissions, promoting the technical level of solar and storage battery systems from the 2020 level to the 2030 level is equivalent to a 1-2 trillion reduction in annual power generation cost. The market potential after future technological innovation can be calculated quantitatively, and the combination of multiple technologies can also show the way to a low carbon society and a sustainable society.

Suggestions on means to implement

- By making capital investment and management decisions to disseminate technology based on quantitative technological evaluation, which can clarify CO_2 emissions, amount of material/resources used, and economics of current and future technology, it is possible to propose win-win measures leading to early low carbon reduction and economic growth.

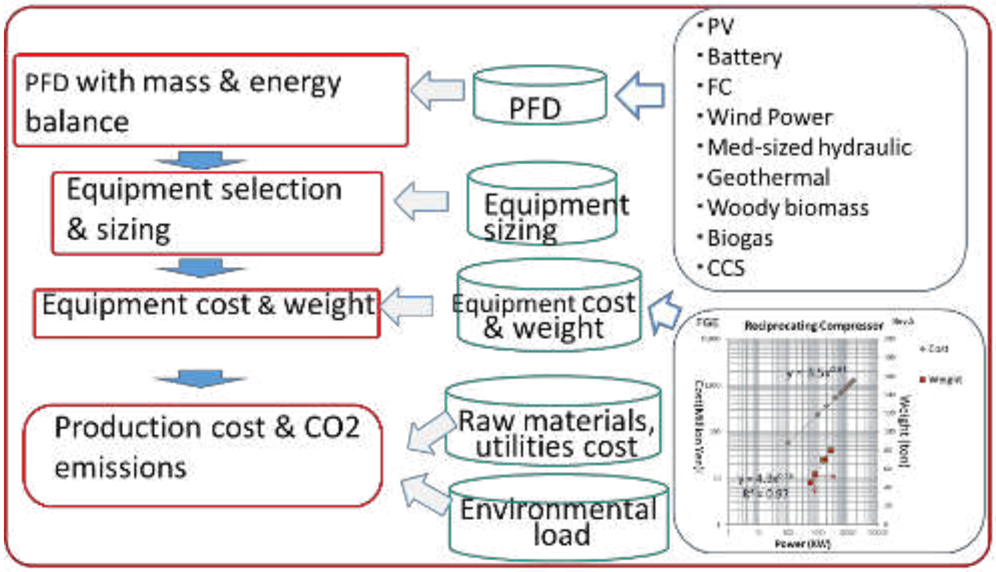


Figure 4 Platform for Design (PFD) & Evaluation: Automated process design support system developed by LCS.

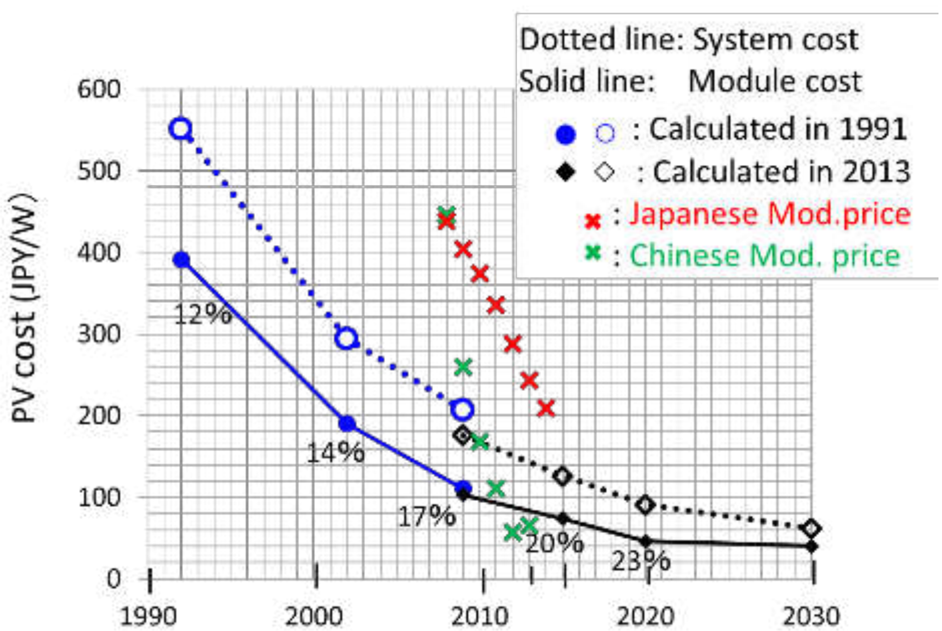


Figure 5 Calculated cost by LCS methodology and actual price of PV module and system (100JPY=1USD).

Source: Komiyama and Yamada, 2018.

Table 2. Renewable energy generation cost calculated from different technology level, Japan

	Facility utilization rate	Power generation cost [JPY/kWh] (Calculation based on LCS tech. scenario)		
		Present tech. (2015 yr. level)	Advanced tech. (2020 yr. level)	Tech. with innovation (2030 yr. level)
Solar	11%	16.0	9.5	5.7
Wind	23%	14.1	10.2	8.4
Geo thermal	70%	12.5	12.5	8.0
Geothermal（Hot dry rock）	70%	-	-	6.9
Biomass	70%	33.6	10.9	10.9
Hydro	54%	10.8	10.8	10.8
Battery	-	50 [JPY/Wh]	10 [JPY /Wh]	6 [JPY /Wh]

Source: Inoue, 2017

Proposal 3: It is necessary to develop and disseminate technology according to the development conditions of each country and region. For that purpose, quantitative technology evaluation should be utilized for investment judgment.

Rationale

- The introduction of a large amount of renewable energy in a future low-carbon society creates a new energy geography. As an example to clarify this, here we take a case of the Middle East region. Tables 3 and 4 shows the power supply structure and cost of Japan and UAE for 80% reduction of CO_2 in 2050, estimated by LCS with cost minimization model. It shows that UAE can achieve an 80% reduction at half cost of Japan's case, due to the amount of available renewable resources, especially solar energy. Moreover, it is assumed that the power demand will increase from the present 100TWh to 700TWh. This amount of power is, for example, an amount that can meet the production of more than half of the world demand for producing aluminum. Thus, it is important to consider optimization of global energy use based on quantitative methodology.

- The size of the market changes with the times due to the change of social system, and it is very important to consider it properly. Depending on the degree of development, the necessary infrastructure technology is different (Figure 6). Especially after basic infrastructure development which is essential to developing countries has progressed, it is shifted to infrastructure investment that takes into consideration the environment and sustainability. It depends on how leap frogging is possible during this transition. Also, as development progresses, it becomes time to introduce advanced systems in such area of information and medical care. At this stage, aiming for higher added value economic activity, we must lead to the development of low CO_2 / GDP.

Suggestions on means to implement

- In order to clarify the investment destination of low-carbon technology, it is necessary to consider the cost information by considering the regional energy situation, natural environment, etc. in a quantitative technology model.

- Making judgments for investment abroad based on reliable market size forecasts by detailed technical evaluations rather than based on current market size only, will provide sustainable scheme for donor developed countries beyond simple aiding system.

- As development progresses, appropriate intergovernmental cooperation and assistance should be promoted, and a highly value-added society will be formed to reduce CO_2 emissions per economic activity.

Table 3. Power Structure and Cost in Japan for 80% and 100% reduction of CO_2 in 2050

Elec. demand (TWh)		800	1,000
Generation Power (TWh)	Nuclear	0	0
	Hydro	130	130
	Coal	24	4
	LNG	257	308
	Solar	441	525
	Wind	2	0
	Geothermal	12	12

	Geothermal（Hot dry rock）	0	100
	Biomass	27	29
	Total	894	1,108
Hydrogen (TWh)		0	0
Storage Battery（GWh）		647	790
Generation Cost（JPY/kWh）		10.7	10.0

Note: inertia regulation is 50%. Estimated by LCS

Table 4. Power Structure and Cost in UAE for 80% reduction of CO_2 in 2015 and 2050

		2015	2050	
Elec. demand (TWh)		100	400	700
Generation Power (TWh)	Nuclear	0	100	175
	Hydro	0	0	0
	Coal	0	0	0
	LNG	109	22	22
	Oil, Other	1	0	0
	Solar	0	298	614
	Wind	0	6	6
	Total	110	426	817
Hydrogen (TWh)		-	0	0
Storage Battery（GWh）		0	200	500
Generation Cost（JPY/kWh）		6.3	5.2	5.4
CO_2 emission （$Mt\text{-}CO_2/y$）		56	11	11

Note: inertia regulation is 25%. Estimated by LCS

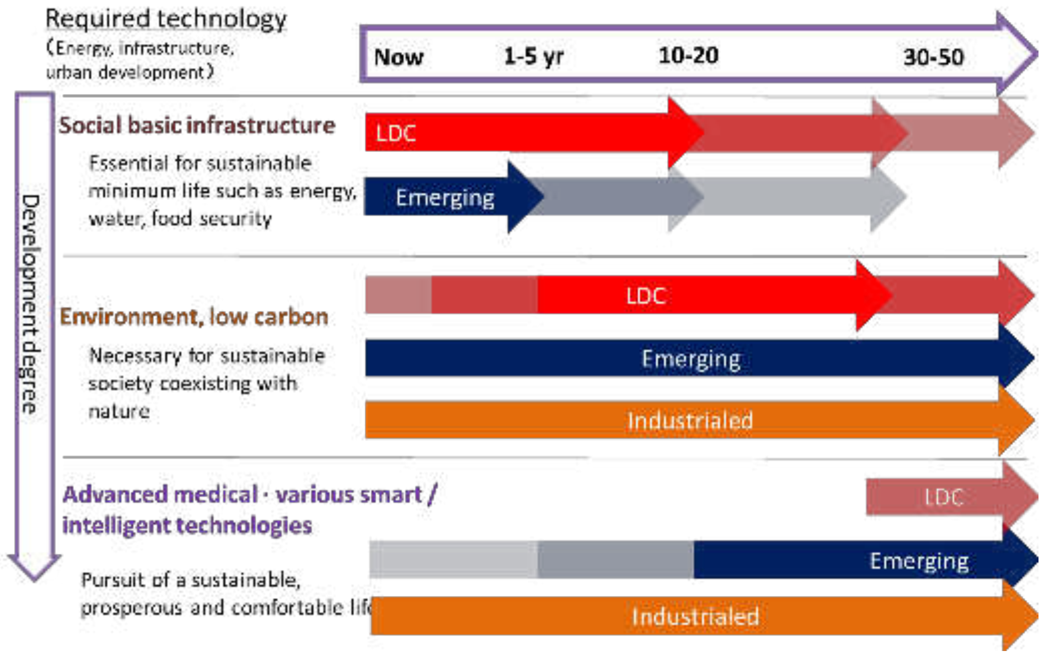


Figure 6 Degree of development and necessary technology, timing

Source: LCS

Proposal 4: From viewpoints of environment, resource and energy efficiency, further improvement and replacement of industries on a global scale is necessary in the future, and a scenario that takes into account the plans for such proper and effective international specialization is indispensable.

Rationale

- In the future society, major reforms have already been foreseen, such as decarbonization of energy and massive increase in material demand due to population and economic growth. The IPCC reported that low-carbon or zero-carbon energy becomes from three to four times of 2010 levels in 2050 at the 450 ppm scenario. In addition, large-scale use of carbon capture and storage (CCS) and bio-energy CCS (BECCS) are assumed. The demand for materials and products in the world has also been rising in the last 40 years (Figure 7), and will increase in the future, considering the future development of the world, which will also increase GHG emissions. In such a largely changing society, it is important to consider the future industrial structure, international cooperation and specialization of industry for optimal production of products and materials. The efforts include energy efficiency, carbon efficiency, material efficiency improvement at the manufacturing stage, and service utilization efficiency at the service utilization stage.

- Fig. 7 shows the correlation between GDP per capita (degree of development) and annual net domestic demand per capita of steel (= apparent consumption - indirect export + indirect import) and social stock. The higher degree of development, the higher net domestic demand (blue) and accumulated amount (orange). In developed countries, there are sufficient stocks and many countries have stabilized net domestic demand. In contrast, developing countries tend to have low stocks but high net domestic demand (blue above orange). The further development of developing countries will result that steel demand continues to increase. For example, in 2100, the world population will increase to 11.2 billion people according to UN estimate. Assuming that the world's average of steel stock per capita is at the current level of developed countries (15 t / capita), society will need 136 billion tons of new steel by 2100. This requires virgin iron instead of scrap iron. (This corresponds to an additional emissions of about 190 billion tons of CO_2). It depends on how clean this amount of new iron can be produced in the future with low carbon technology. It is clear that further efforts for global technical cooperation and low carbonization are important.

Suggestions on means to implement

- The future industrial structure will change. It is important to look at future industrial structures from the long-term social image that takes into consideration progress of innovative technologies such as IT and AI and structural change of energy supply and demand, population and labor. We should identify the basic material manufacturing industries required for social infrastructure and new low-carbon industries to be promoted that can produce high added value.

- In order to reduce carbon, resources, materials and products used on the earth are handled by international cooperation and international division of labor. Establish a framework of international partnership for that purpose.

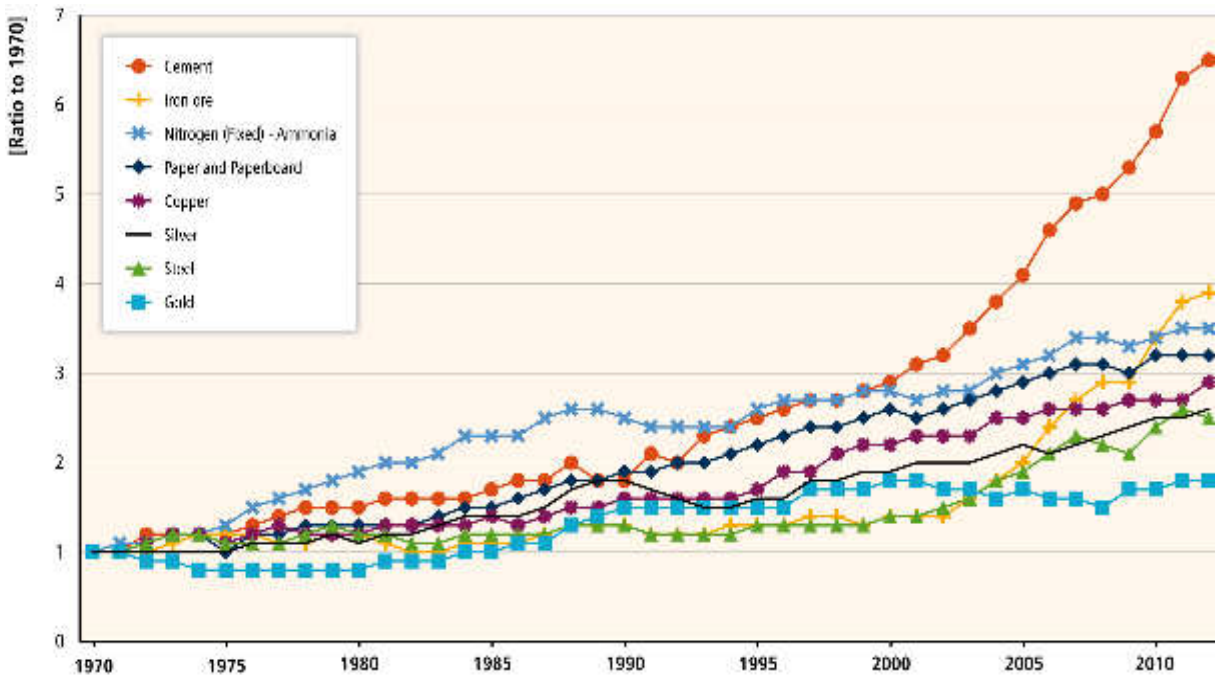


Figure 7 World Materials and Products Trend

Souce: IPCC 2014

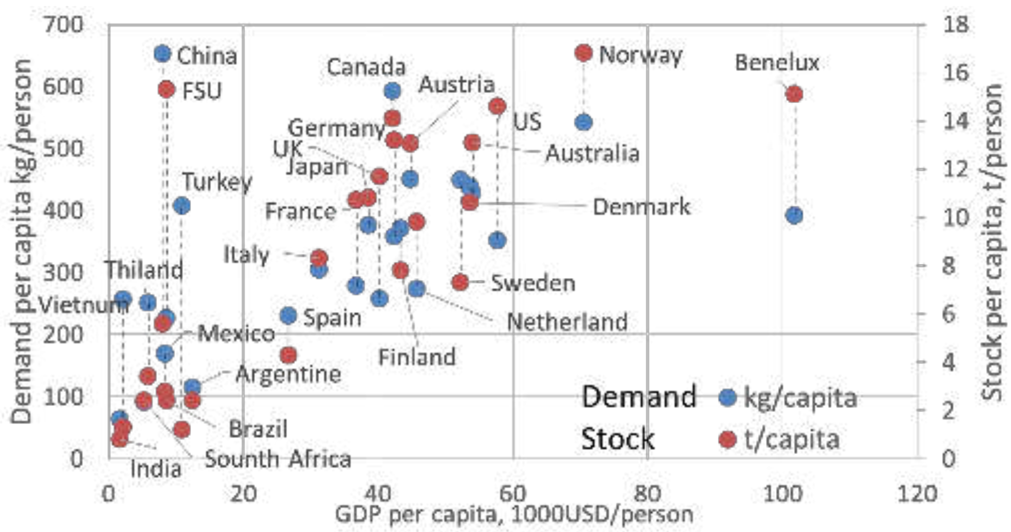


Figure 8 Correlation between degree of development and net domestic demand and stock of steel

Souce: Tanaka, 2019

Proposal 5: Showing relationship between results of quantitative technology scenarios and evaluation methods of industrial structure change is a foothold for creating new industries with high economic benefit. .

Rationale

- The model using the input-output table so far has not clarified the spillover effect when new technology is introduced into society or society is transformed. Therefore, LCS has developed a new input-output table model that enables spillover assessment using ECCC. Economic impact and total CO_2 emissions when using zero carbon power source are shown in Table 5 using the new assessment model based on input-output table developed by LCS (Figure 9) (Yamada, 2019). It is assumed that other energy use is the same as the current situation, so decarbonizing the power supply will reduce CO_2 emissions only to 63%. For further reduction, it is necessary to cover fossil fuel utilization currently consumed as thermal energy with decarbonizing power and to reduce carbon emissions from industrial processes.

- Not only decarbonization of power supply, but also social change is important. For example, by promoting tourism, advanced health care, application of electric vehicles, enhancing education and communication, high functional steel use and energy saving at residential and industry sectors (*), CO_2 will be reduced to 43% and CO_2 / GDP will be reduced to 0.96 g-CO_2/JPY.

Suggestions on means to implement

- Efforts to decarbonization should be discussed in the overall social image, using a model that can assess what kind of spillover effects are existing in the whole industry. This makes it possible to consider the proposal of a new social system and its economy-wide impact.

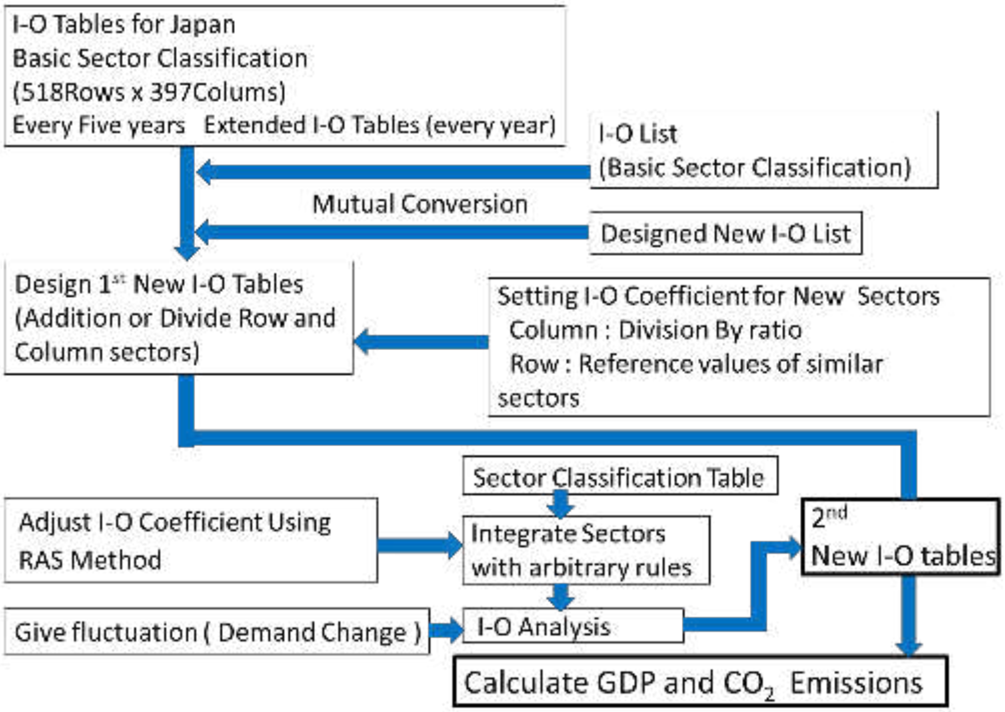


Figure 9 Model structure of LCS new Input-Output model.

Table 5 GDP and CO_2 emissions with zero-carbon power structure, using new LCS Input-Output model

	Unit	2011	Decarbonized power structure	Decarbonized power structure and new social systems (*)
GDP	Trillion JPY	489	493	563
CO_2 emissions	Mt-CO_2/yr.	1254	794	543
CO_2/GDP	g-CO_2/JPY	2.56	1.61	0.96

Note: Electricity demand is 992 TWh/Yr.

Source: Yamada, 2019

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