IGES Research Report

A Net-Zero World -2050 Japan-

Insight into essential changes for a sustainable future

IGES
Institute for Global Environmental Strategies

Integrated Climate Change Team supported by Strategic Research Fund

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IGES
Institute for Global Environmental Strategies

Foreword

Hideyuki Mori, Special Policy Advisor and former Executive Director, IGES

I am pleased to present this report entitled *Net-Zero World: Japan 2050*. As illustrated by the COVID-19 crisis, it is anticipated that there will more uncertainty in the world, and this report shares one vision for the future. Going forward, IGES plans to supplement this report with additional work that considers issues such as technological innovation, international discussions on climate change, and their relevant policy implications.

This report aims to build an understanding of what a net-zero world would be like. It does so by imagining our society 30 years from now using the perspective of climate change by quantitatively analysing energy demand and greenhouse gas (GHG) emissions and envisioning what our day-to-day lives could be like.

Predicting the future is not easy, and there are many possible ways to envision it. However, we believe that it will become increasingly important for each one of us to contemplate what kind of society we will build.

We are releasing this report in the hope that it can become a starting point for constructive discussions among many stakeholders on how Japan ought to move towards net-zero emissions.

In Europe, the European Green Deal was released at the end of 2019. It provides specific guidelines on how the region can achieve net-zero emissions by 2050. The European Green Deal's comprehensive and specific guidelines include the "circular economy" approach, justified in part by the climate crisis. I believe many people saw this as a reflection of Europe's extraordinary determination to take bold steps towards societal transformation. Many expect that Europe, along with China, will continue to lead international discussions on climate change.

Asia is largely dependent on coal-fired power generation and this has been heavily criticised as a "coal addiction". Under such circumstances, even in Japan, too much emphasis is placed on mitigating the negative impacts of zero-carbon transformation. As a result, discussions and initiatives to achieve a net-zero society have not necessarily progressed in an ideal way.

Given this situation, the Japanese government established the "Beyond Zero" Initiative to deploy technological innovations to substantially reduce CO_2 emissions. Moreover, the Japan Business Federation (Keidanren) has also started its "Challenge Zero" Initiative to encourage and promote the results of innovative efforts by individual companies, as well as providing financial support. On top of this, 158 local governments have already declared their intention to "achieve net-zero carbon dioxide emissions by 2050" (as of 8 October 2020). In Japan, with major stakeholders leading the way, the momentum toward net-zero is steadily growing.

Within this context, it is my hope that the vision for society and the estimates shown here will help facilitate discussions on how to make a vibrant "decarbonised society" that leaves no one behind.

Executive Summary

In recent years it has become clear that anthropogenic climate change has the potential to seriously affect our lives, by causing severe weather events that lead to wind and flood damage, and impacting areas such as agriculture and food security, conservation of water resources, coastal areas and oceans, as well as human health. As a result, according to the IPCC and other actors, it is necessary to design a net-zero world (in which GHG emissions are equivalent to absorption) by 2050, and substantially reduce the use of fossil fuels, which are responsible for most carbon dioxide (CO_2) emissions. Given this context, various actors including central governments in Europe, other national and local governments, and financial institutions are moving forward with initiatives aimed at achieving net-zero emissions.

As global climate change is experienced, various social and technological developments are also being made. These include the rapid deployment of renewable energy, new mobility options, progress in digitalisation through advances in AI and ICT, creation of a sound material-cycle society as a basis for improvements in resource efficiency and handling waste, and resilience to adapt to a 1.5ºC or 2ºC rise in temperature. Moreover, there has been progress on policies to promote the formation of "circulating and ecological spheres" that contribute to regional revitalisation in Japan by creating more independent and decentralised societies, while also complementing and supporting local resources in nearby localities.

The level of economic growth, which influences the amount of energy used to produce goods and services, is a fundamental factor determining the sustainability of daily life and society. In Japan, annual per capita GDP growth averaged 0.5% from 2005 to 2015. Additionally, the essence of capitalism — expressed as 'unlimited expansion and growth' — is recognised as causing society to reach a limit, both materially (in terms of the finite nature of planetary resources) and spiritually (in terms of "happiness"). In response, concepts such as "de-growth" and "creatively steady-state economies" have become increasingly recognised in recent years.

Based on this situation, Chapter 1 used a bottom-up approach to estimate how various social changes would affect energy use, material use and GHG emissions. It assumed that per capita GDP growth will be 0.6% and that the Japan's overall GDP will remain flat at 2015 levels. This analysis used two scenarios: **1) a transition scenario (which assumes fundamental transformations in existing social, economic, and infrastructural systems as the result of international trends, social/ domestic issues in Japan, and technological development), and 2) a lock-in scenario (which assumes almost no fundamental transformations due to these various circumstances).**

Regarding energy systems, in the transition scenario, progress would be made in electrification of households, businesses, transportation and manufacturing. The energy use for sectors is assumed to be efficient. For manufacturing, there would be progress in the use of hydrogen for some processes requiring high temperatures, as well as chemical production. Moreover, a net-zero world would be achieved by supporting people's lives and economic activities through the use of non-fossil fuel energy (mainly renewable energy). On the other hand, while energy efficiency in the lock-in scenario would improve considerably in households, businesses, transportation and manufacturing, the energy system is assumed to be based on an extension of current energy technologies and systems. Thus, in this scenario, a net-zero world would (somewhat forcibly) be achieved through the massive use of Carbon dioxide Capture and Storage (CCS) and negative emissions technologies, and people's lives and economic activities would continue to be supported by fossil fuels.

Chapter 1 also estimated energy consumption by type of fuel as well as CO_2 emissions and storage use for each scenario. It then compared the necessary level of renewable energy for these scenarios as well as the renewable energy potential. In addition, the amount of CO_2 storage use was compared with the domestic CO_2 storage potential. Finally, the amount of imported fossil fuels was calculated. As a result, the chapter concluded that the transition scenario would be able to reduce any risks associated with CO_2 storage and greatly improve energy security by overcoming the dependence on fossil fuel. Moreover, if Japan used the monetary value of fossil fuels (amounting to JPY 19 trillion as of 2015) for other purposes, it would be easier to mobilise the necessary investments to more extensively transform society, such as those for independent or decentralised renewable energy infrastructure (e.g. strengthening transmission and distribution networks, installing EV charging stations). It was also found that in the transition scenario, domestic renewable energy potential could satisfy energy demand, owing to improvements to energy efficiency, even though most of the energy comes from renewables.

On the other hand, a net-zero world in the lock-in scenario may be achieved, but would be based more on existing technologies. However, the results showed that the net-zero world in this scenario would constantly be faced with various risks, including rising CO_2 levels and their related storage costs (highly uncertain), and energy security due to continued dependency on fossil fuels from oil- and coal-producing countries, which could also exacerbate the trade balance. Chapter 1 concluded that the transition scenario has fewer risks and is the more suitable direction for Japan to achieve a net-zero world.

Chapter 2 examined the visions for a net-zero world through the lens of cities, rural areas, daily life, industry and adaptation, due to social changes brought about by the transition scenario. Today's Japan faces various challenges including demographic issues such as declining birth-rate and ageing population, social welfare concerns related to pensions, labour matters such as long working hours and non-regular employment, social inequality, and a variety of natural disasters. Therefore, the transition scenario assumes that there will be various changes in society that result from countermeasures and technological innovations to address those issues. In fact, it is not easy to accurately predict how our day-to-day lives will change. Chapter 2, therefore, aimed to provide some understanding of what daily life and economic activity will be like in a net-zero world under the transition scenario.

Chapter 3 described issues and challenges related to the transition towards a net-zero world, including a just transition, and provided the logic for realising a net-zero world. In particular, the chapter acknowledges the importance of careful discussions about the feasibility of creating net-zero societies and the treatment of possible negative impacts. At the same time, it showed the importance of having a broader and longer-term perspective as well as the potential opportunities that may arise as a result of achieving net-zero emissions in society.

A net-zero world will require fundamental transformations in systems and practices across every sector. This is not something a single organisation can do on its own; it must be addressed with a national-level strategy, and all relevant actors in Japan must work in alignment. It is particularly necessary to make progress on increasing the share of renewables so that they become a major power source, as well as reform existing power systems to enable this. At the same time, we need to take every opportunity to make improvements to infrastructure that will be used over the long term (such as buildings, large-scale power stations, and industrial facilities), so that the built environment can adapt to major social changes in the future. This will require a substantial number of advanced preparations and long-term reforms.

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Glossary

3R	Reduce, Reuse, Recycle
AI	Artificial Intelligence
APF	Annual Performance Factor
BDI	Bundesverband der Deutschen Industrie
BECCS	Bio-energy with Carbon Capture and Storage
BNEF	Bloomberg New Energy Finance
CCS	Carbon dioxide Capture and Storage
CCU	Carbon dioxide Capture and Usage
CDP	Carbon Disclosure Project
CFRP	Carbon Fibre Reinforced Plastic
CH4	Methane
CLT	Cross Laminated Timber
CNFRP	Cellulose Nanofiber Reinforced Plastic
CO_2	Carbon Dioxide
COP	Conference of the Parties
DAC	Direct Air Capture
DACS	Direct Air Capture and Storage
EC	Electronic Commerce
EPA	Environmental Protection Agency
ESG	Environmental, Social, and Governance
ETC	Energy Transitions Commission
EU	European Union
EV	Electric Vehicle
FCV	Fuel Cell Vehicle
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GSDR	Global Sustainable Development Report
GWP	Global Warming Potential
HCFC-22	Hydrochlorofluorocarbons
HFCs	Hydrofluorocarbons
HFO	Hydrofluoroolefin
ICT	Information and Communication Technology
IGES	Institute for Global Environmental Strategies
IH	Induction Heating
IIASA	International Institute for Applied Systems Analysis
IRENA	International Renewable Energy Agency
IoT	Internet of Things
ITF	International Transport Forum
IPCC	Intergovernmental Panel on Climate Change
JCM	Joint Crediting Mechanism
JST	Japan Science and Technology Agency
LED	Low Energy Demand
MaaS	Mobility as a Service
MIROC	Model for Interdisciplinary Research on Climate
N_2O	Nitrous Oxide
NDC	Nationally Determined Contribution

NET	Negative Emission Technology
NF_3	Nitrogen Trifluoride
NPO	Non Profit Organisation
PC	Personal Computer
PFCs	Perfluorinated Compound
PFN	Perfluoronitrile
PHV	Plug-in-Hybrid
PRB	Principles for Responsible Banking
PRI	Principles for Responsible Investment
PSI	Principles for Sustainable Insurance
RCP	Representative Concentration Pathways
SCC	Social Cost of Carbon
SDGs	Sustainable Development Goals
SDSN	Sustainable Development Solutions Network
SF_6	Sulphur Hexafluoride
SRES	Special Report on Emissions Scenarios
SROCC	Special Report on the Ocean and Cryosphere in a Changing Climate
SSPs	Shared Socioeconomic Pathways
TCFD	Task Force on Climate-related Financial Disclosures
TEN-E	Trans-European Networks-Energy
UNEP	United Nations Environment Programme
VPP	Virtual Power Plant
VR	Virtual Reality
V2G	Vehicle-to-grid
WBA	World Benchmarking Alliance
WBCSD	World Business Council for Sustainable Development
ZEB	Net Zero Energy Building
ZEH	Net Zero Energy House

Structure of this report

This report explores how Japan can make the transition to net-zero.

It is organised into three chapters. Chapter 1 presents a quantitative analysis of energy demand trends for net-zero societies, setting 2050 as the target year. Chapter 2 provides qualitative descriptions of what a net-zero world could mean for day-to-day life. Chapter 3 then explains the main potential challenges and objections to a transition to net-zero society.

Chapter 1 focuses on two scenarios for net-zero emissions: 1) the case where large-scale societal change is realised ("transition scenario") and 2) the case without such large-scale changes ("lock-in scenario"). Through these two scenarios, the chapter considers the kind of energy system that could be realised by quantitatively illustrating aspects such as GHG emissions and absorption, energy consumption, renewable energy use, changes in the amount of CO_2 that needs to be absorbed, and energy supply.

Chapter 2 then provides a narrative to describe the image of what society would look like after major transformations in economic, energy and social systems and more. To accomplish this, technological, social and personal trends for 2030, 2050 and 2100 were compiled from various published sources (details available in appendices), and through expert interviews. The narrative primarily describes those elements that were deemed most feasible. While it is possible that the world 30 years from now (2050) will be vastly different from our current world because of technologies and values that do not yet exist, this report describes 2050 with some optimism.

Next, Chapter 3 provides an overview of various issues and challenges involved in creating net-zero societies. It concludes by proposing several social changes, including some related to a "just transition". This report aims to send an important message that, for the sake of the survival of humankind, decisions and actions must be taken to trigger the transformation of society.

While this report shows the preliminary results of analysis to describe a net-zero world, we will continue to pursue related research topics, through additional exchanges with a range of stakeholders, and further analysis.

Introductory Chapter: Thinking about Net-Zero Societies
Identifying future technologies, social issues, and international issues

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Chapter 1: Estimating the Net-Zero Society (Scenario Formulation)
Lock-in scenario: Technological progress in a society in which existing social systems and policies are maintained
Transition scenario: Technological progress that involves transformations in various societal elements

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Chapter 1: Estimating the Net-Zero Society (Estimation of GHG Emissions, etc.)
Evaluating individual literature on the societal impacts of each technological development and solution to issues
Quantifying societal changes that affect energy use
Comparisons: *necessary amount of renewable energy, emission reduction due to societal change, necessary amount of CCS, amount of fossil fuel imports*

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Chapter 2: Prospects of a Net-Zero Society

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Chapter 3: Toward Realising a Net-Zero Society

Figure 1 Structure of this report

Introduction: Considering a Net-Zero World

The Dawn of a New Society

Humankind has built an advanced civilisation, having progressed from hunter-gatherer to agrarian societies, then to an industrial and now an information-based society. Upon reflection, we can see that energy has been a key supporting element for this expansion of human activity. We can say that humans began by using the natural phenomenon of fire, and by making successive discoveries and constantly striving to create and improve, came to make use of modern energy on a vast scale, whether it be electricity derived from fossil fuels, or from nuclear power.

However, in recent years it has become clear that anthropogenic climate change has the potential to seriously affect our lives, with adverse impacts such as storm and flood damage, agriculture and food insecurity, depletion of water resources, degradation of coastal ecosystems and oceans, as well as threats to human health. Given that climate change is mainly caused by carbon dioxide (CO_2) emitted from the fossil fuels that are used to support most socio-economic activities, the global community is faced with the urgent issue of replacing this energy source. For the sake of global climate stability as well as survival of all life on the planet (including humans), many people are becoming aware that we need to realise a world where the amount of greenhouse gases (GHG) emitted and absorbed cancel each other out — in other words, a net-zero world. Under these circumstances, renewable energy, such as solar and wind power generation, is already cost-effective for practical use and diffusion. With further improvements in energy storage and related technologies, the role and importance of renewables in supporting socio-economic activities will increase. We can already see this happening in the transport sector, a major consumer of fossil fuels. The transition from traditional vehicles equipped with internal combustion engines to those that are electric or use fuel cells has already started, and there is now an increasing market for these new options. Turning to the building sector, progress is being made to transition existing homes and other buildings into zero emission houses (ZEHs) and zero emission buildings (ZEBs).

There is finally a sense of crisis that voluntary actions by companies and industries[1] alone are insufficient, leading to prominent moves from the financial sector to accelerate GHG emissions reductions. Among financial institutions, mainly in North America, there have been changes in response

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[1] In Japan, the Japan Business Federation's "Keidanren Voluntary Action Plan on the Environment" has been continuously implemented since 1997, and since 2013 this plan has been adapted to become the "Action Plan for Low-Carbon Society", prompting further voluntary initiatives. The plan consists of four pillars: emission-reduction measures for domestic business activities that have already been implemented, strengthening of cooperation between actors (for reducing emissions in manufacturing, etc.), promotion of international contributions, and development of innovative technologies [136].

to climate change, including further divestment from fossil fuels and greater flows into ESG investments such as green bonds. The three principles of sustainable finance[2] have also been established. Many companies have worked on the Task Force on Climate-related Financial Disclosures (TCFD) activities[3] to promote climate change countermeasures by disclosing climate-related information based on the Principles for Responsible Investment, and this information is useful for investors.

Many relevant institutions, including institutional investors, insurance companies and banks are participating, becoming the "switchmen"[4] that support this path.

At the United Nations Climate Action Summit in September 2019, according to the Special Report of the Intergovernmental Panel on Climate Change (IPCC)[5], net-zero emissions by 2050 (which is based on the 1.5ºC target) became a benchmark for measuring national ambitions. At that point, 59 countries announced their intention to raise their Nationally Determined Contributions (NDCs) by the end of 2020; domestic processes had already begun in 11 countries. Moreover, 66 countries or regions, 10 states, 102 cities, 87 companies, and 12 financial institutions have since declared their intention to achieve net-zero emissions by 2050 or otherwise accelerate the momentum towards this goal. In total, countries, regions and cities that together make up over 15% of global emissions have expressed their goal to achieve net-zero emissions by 2050. On 14 January 2020, Chile, which holds the COP25 Presidency, announced that 108 nations have expressed their intention to update and resubmit their NDCs in 2020 [1]. The NDCs are required by the Paris Agreement, and are made up of national targets for GHG emissions reduction, as well as climate change countermeasures. If these targets and measures are combined with trends seen in the private sector and financial institutions, then it becomes clear that there is significant potential to create greater momentum for decarbonisation. While Japan did not commit to halting the construction of new coal-fired power plants at COP25, there was a shift in the way the international community discussed the 1.5ºC target, and this may strengthen opposition to coal power.

A recurring issue that is being re-evaluated is the use of GDP as an economic development target and assessment criteria. For instance, a new index is being proposed to measure national wealth from

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[2] Specifically, the three principles are as follows: Principles for Responsible Investment (PRI) in 2006, Principles for Sustainable Insurance (PSI) in 2012, and Principles for Responsible Banking (PRB) in 2019.

[3] Task Force on Climate-related Financial Disclosures (TCFD): As of 1 March 2020, of the 1,027 organisations that have expressed their support for the purpose of the recommendations, 251 organisations are Japanese, making Japan the country with the greatest number of institutional supporters globally.

[4] While switchmen are no longer commonly seen, this term refers to those who are responsible for handling the railroad switches.

[5] Intergovernmental Panel on Climate Change: The United Nations Environment Programme (UNEP) and the World Meteorological Organisation (WMO) co-organised the first meeting in 1988. Based on scientific knowledge around the world, an internationally influential report was published that details the mechanism of climate change, the impacts on the environment and socioeconomics, and principles of countermeasures.

a sustainability perspective, focusing on the value of natural and social capital.

Climate change countermeasures include countries' introduction of carbon pricing to internalise the cost of emissions from economic entities and to provide price signals by adopting tax reforms and other relevant measures. The purpose of carbon pricing is to reduce emissions from all economic actors, via price signals. Another example of a policy evaluation tool [4][6], used in the United States, is the social cost of carbon (SCC), a financial index illustrating the climate change-related damages caused by carbon emissions [2][3].

In this way, various elements for creating a new net-zero world are already being developed in major sectors such as energy (technologies and policies), transport, construction and manufacturing (decarbonising technologies), and finance (values or codes of conduct). These elements or building blocks, which can be broadly defined as net-zero infrastructure, serve as the foundation for creating a new society. Momentum is growing across the entire international community to promote this infrastructure nationally and create new industries and employment, while leaving no one behind — a call for a just transition toward a net-zero world.

[6] The SCC is an index to measure the extent to which companies and individuals, after recognising the impacts of climate change (damage due to heavy rain or floods, etc.) and acting to reduce emissions on their own accord, can obtain the benefits (in terms of avoidance of damage from climate change impacts). Thus, it can be a driving force to promote emissions reduction.

The Importance and Urgency of Designing a Net-Zero World

The IPCC's Fifth Assessment Report showed the relationship between the cumulative amount of anthropogenic GHG emissions (the sum of annual emissions in human history) and the planet's temperature rise. It is a fact that mankind has been releasing GHGs. As long as these emissions continue, temperatures will rise and we will continue to see an increase in wide-ranging damage from storms and flooding, threatening human existence itself[7]. This illustrates the importance and urgency of halting the rise in GHG concentrations globally — that is, transitioning to a net-zero world. This is not a global issue that can be negotiated; rather, it is a phenomenon based on the laws of nature, and one whose resolution requires the collective strength of all of humanity. In other words, it does not make much sense to continue debating whether or not it is possible to achieve net-zero emissions. Instead, we are reaching the point when stakeholders must seriously consider when and how to achieve net-zero emissions and take prompt action.

The Paris Agreement adopted in December 2015 set long-term temperature targets to limit global warming to "well below 2°C" and pursue efforts to limit warming to 1.5°C. However, the differences in adverse impacts between a 1.5°C rise and 2°C rise, as well as the potential emission pathways limiting the rise to 1.5°C, were not sufficiently considered in the IPCC's Fifth Assessment Report (2013/2014). Since there was also a lack of scientific knowledge on the subject, the Conference of the Parties (COP) of the United Nations Framework Convention on Climate Change requested that the IPCC consolidate what was known regarding the 1.5°C target. The result was the IPCC Special Report on Global Warming of 1.5°C, released in 2018[8]. The report raised awareness in the international community on the importance of limiting warming to 1.5°C, and it covers a wide range of issues. Some of its main points are outlined below.

1. Since the Industrial Revolution, human activity has resulted in a 1°C rise in atmospheric temperature. The impacts of this temperature rise are already being seen.
2. Going forward, the risks of a 1.5°C temperature rise will have a greater negative impact than at present, and a 2°C rise will be even more devastating (Table 1).
3. To limit warming to 1.5°C, it is necessary to reduce global emissions by 45% by 2030 (compared to 2010 levels) and achieve net-zero emissions by around 2050. (To limit warming to 2°C, net-zero

[7] Research suggests that, when a certain tipping point is reached, warming will become uncontrollable and lead to a 'hothouse Earth' [86].

[8] The official title of the report is "Global Warming of 1.5°C: An IPCC Special Report on the Impacts of Global Warming of 1.5°C Above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development and Efforts to Eradicate Poverty".

emissions must be achieved by around 2075.)

4. If GHG emissions are only reduced by the level set out in the current 2030 targets, it will be almost impossible to limit warming to 1.5°C, even if further emission reductions can be achieved after 2030.

The IPCC has also released other important special reports, including the *Special Report on Climate Change and Land, and the Special Report on the Ocean and the Cryosphere*[5]. They are sounding the alarm for international society.

The climate change impacts suggested in the IPCC Special Report are already starting to be seen in Japan, including damage from heavy rain and typhoons. For example, the Japan Meteorological Agency's official view is that the heavy rains in West Japan in 2018 were linked to climate change. The total amount of insurance payout for natural disasters in 2018 was the highest in history, at JPY 1.6 trillion [6]. It is important to note that the damage caused by climate change — such as that from the catastrophic typhoon in 2019 — is likely to continue worsening from now on. Thus, in order to minimise the negative impact of climate change and build a safe and secure society, it is important for Japan to set a goal to achieve net-zero emissions — that is, realise a net-zero world — as soon as possible, and start with measures that can be taken today.

Table 1 Climate Change Impacts

	Regions	1.5℃	2℃	Adaptation	Adaptation Potential
Agriculture and food security	Global, Africa, Asia	32-36 million people affected by reduced yields	330-396 million people with reduced yields	Climate resistant varieties, irrigation	Medium: higher in high latitudes than in low latitudes
Water resources	Global, Africa, Mediterranean region	469 million people water-stressed	590 million people water-stressed	Rationing wells, rainwater tanks	Low
Coral reefs	Tropics	70-90% at risk of loss	99% at risk of loss	-	Very limited
Coastal settlements	Global, Asia, Small Island Developing States	31-69 million people at risk	32-79 million people at risk	Coastal, mangrove	Low to medium: some atolls may become uninhabitable at 1.5°C /2°C
Health	Global, local, tropical regions	+350 million people exposed to deadly heatwaves in megacities by 2050		Hydration, cooling zones, green roofs	Medium, low in the tropics

Reference: R. Mechler [7] at the IPCC Side Event during COP24 based on IPCC Special Report on Global Warming of 1.5°C (Chapters 3-5)

Notably, it is thought that the novel coronavirus (causing the COVID-19 disease) emerged in part due to ecosystem loss caused by climate change and unsustainable development, and the resulting increase in complex interaction between humans and wildlife. Globalisation — the instantaneous transboundary movement of humans, goods, money and information — then enabled the virus to spread rapidly, leading to a global pandemic. We must not forget that this crisis is rooted in the vast environmental changes caused by unsustainable development.

Given the IPCC Special Reports, as well as the many extreme weather events being experienced, many countries aim to limit warming to 1.5ºC. Some countries have been working proactively to achieve net-zero emissions as one of their national medium-term to long-term strategies.

In September 2019, the Climate Ambition Alliance was established. This initiative calls for its members to raise their NDCs by 2020 or commit to net-zero emissions by 2050. In the future, it is estimated that more countries will support this initiative.

The EU released "A Clean Planet for all — A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy by EU" in November 2018, with a scenario to achieve net-zero by 2050. Based on this, on 12 December 2019, the European Council endorsed the objective of achieving carbon neutrality by 2050[9]. Moreover, the European Parliament is considering a vote to raise the target. In December 2019, the "European Green Deal" ((COM2019) 640) was formulated and published, which states that the EU countries will work together to make far-reaching and proactive efforts toward tackling the most urgent issues in Europe and boldly promote social change (see Box 1).

In March 2019, the UK announced its strategy to achieve net-zero carbon dioxide emissions in "Net-Zero: the UK's contribution to stopping global warming" [8]. On 27 March 2019, the bill to revise the 2008 Climate Change Law was passed, institutionalising the net-zero policy target. In response, industrial sectors in the UK have begun to develop strategies to decarbonise [9]. Similarly, France passed a bill on 8 November 2019 that required the country to achieve carbon neutrality (net-zero) by 2050 [10].

To achieve net-zero emissions, it is vital to decarbonise the industrial sector, and there have been ongoing discussions about this in Europe. The Federation of German Industries (BDI) released a report on decarbonisation in January 2018 [11]. The BDI's report showed that existing measures could achieve a 61% reduction in GHGs (compared to 1990) by 2050 and outlined a pathway to a 95% reduction. It is anticipated that the decarbonisation trend will lead to maximum reductions in fossil fuel use for the transport sector, including the Port of Rotterdam, home to the majority of petrochemical plants owned by the British-Dutch oil giant Royal Dutch Shell. An initiative by the Rotterdam Port Authority is the basis for a pathway to decarbonise the industry [12]. In addition to this, research institutes and other organisations have published numerous reports that describe specific measures to decarbonise industry [13–20].

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[9] However, one country (Poland) abstained [137].

Meanwhile, Japan's "Long-term Strategy under the Paris Agreement", formulated in June 2019, stipulates "a decarbonised society as the ultimate goal", and that the country is "aiming to accomplish it ambitiously as early as possible in the second half of this century". In January 2020, based on this document and the "2019 Integrated Innovation Strategy" (provisional translation), the Japanese government's Integrated Innovation Strategy Promotion Council (provisional translation) agreed on the "Innovative Environmental Innovation Strategy" (provisional translation). Since September 2019, Japan has also been a member of the Carbon Neutrality Coalition, which aims to create a decarbonised society [21].

Momentum is not limited to the national level; at the provincial and local levels, there is active momentum toward net-zero emissions. According to the UNEP Emissions Gap Report [22], at the subnational level, eight states and 32 cities in the world have declared net-zero emissions goals (as of September 2019) (see Table 2). In Japan, 158 local governments (22 prefectures, 86 cities, one special ward, 39 towns, and 10 villages) have made Net-Zero Declarations — to "achieve net-zero carbon dioxide emissions by 2050" — pioneered by Tokyo, Kanagawa Prefecture and Yokohama City. The cumulative population of these local governments is roughly 63.7 million people, which is more than half of the total Japanese population, accounting for roughly JPY 310 trillion of GDP (as of 27 May 2020) (see Figure 2). In this way, momentum toward building a net-zero world is also becoming more prominent in Japan, with the belief that creating a specific vision toward this goal will contribute to deepening discussions on policies, measures, research and other related activities.

The COVID-19 pandemic that unexpectedly emerged at the beginning of 2020 re-emphasised the importance and urgency of designing a net-zero world. Firstly, the pandemic heightened the recognition that, if humans continue to impact the climate and ecosystems at this current pace, then there is a possibility that we will continue to experience crises similar to or even more serious than COVID-19. While the causes of the COVID-19 outbreak are still under investigation, a likely hypothesis is that the virus was transmitted from wildlife to humans (a zoonotic infection). In this era known as the "Anthropocene", humans are continuously disrupting ecosystems by encroaching on wildlife habitats.[10] The crisis has made us recognise once again that human-induced instability of the natural world may, at times, develop into a fierce battle for human survival.

Secondly, the crisis demonstrated that, when it is truly necessary, human beings are able to change behaviours and social structures that have become routine and automatic. Nationwide lockdowns or other measures to keep people from going outside have led to accelerated progress on remote working and distance learning. Even in Japan, which had been slow to adopt remote work, there have

[10] Koichi Goka of the National Institute for Environmental Studies describes this as "a human-induced disturbance of co-evolutionary relationships between hosts and parasites". [138]

been adjustments in workstyles and lifestyles. This has started to create significant changes in work-life balance as well. Even those people who were concerned about rapidly transitioning to a net-zero world have begun to recognise that change is necessary and, more importantly, that it is feasible.

Thirdly, related to COVID-19 and the transition to a net-zero world, many people have called for a more sustainable, resilient and inclusive society. Regarding the medium-term economic recovery phase that needs to follow strong measures to contain the infection in the short-term, there are demands for measures to 'build back better' — to build a society that is better able to respond to similar crises. Going forward, the large-scale economic measures implemented in each country should be similar to the above-mentioned European Green Deal, thereby leading to the implementation of a Green New Deal at the global level. During the 11th Petersberg Climate Dialogue[11], held virtually on 27-28 April 2020, 27 ministerial delegates, including the Japanese Environment Minister Shinjiro Koizumi, discussed the "green recovery" approach that integrates both economic recovery from COVID-19 and climate change countermeasures. Setting such a precedent through this dialogue can be seen as a major step.

COVID-19 is an issue that is closely related to sustainability, and integrated measures must be taken in the short-, medium- and long-term.[12]

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[11] For more information, visit the German Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety's official website: https://www.bmu.de/en/petersberg-climate-dialogue-xi/

[12] For more information, please read the IGES Position Paper, Implications of COVID-19 for the Environment and Sustainability, available here: https://www.iges.or.jp/en/pub/covid19-e/en.

Box 1 European Green Deal

The document, released in December 2019, covers a wide range of topics and outlines plans to proceed with "deeply transformative policies," as outlined below:

- Raise the 2030 and 2050 targets pertaining to climate change: Propose a European Climate Law that will become the legal basis for the 2050 climate-neutrality target by March 2020. Based on this law, strengthen the 2030 target from 40% to 50-55% reduction.
- Clean energy supply: Recognise that the electricity sector needs to be based mostly on renewable energy; quickly phase out coal and decarbonise gas, in light of the strengthened 2030 and 2050 targets. The European Commission (EC) should assess the ambition of energy and climate plans that must be submitted by Member States during 2019, and, if necessary, translate them into EU energy legislation by June 2021. Member States are expected to incorporate the new targets when revising their plans in 2023.
- Rebuild industry toward a clean circular economy: Given that the steel, chemical and cement industries are indispensable to the European economy, recognise the need to decarbonise and modernise these industries, and develop hydrogen reduction technology to produce iron by 2030.
- Improve energy and resource efficiency in buildings: Increase the current 1% rate of renovation two- or three-fold. To do so, examine the implementation status of member countries' long-term renovation strategies in 2020 and strictly enforce related laws regarding energy performance in buildings.
- Accelerate the shift to smart transport/mobility: Strengthen CO_2 emission regulations for passenger vehicles by June 2021 to make considerable air quality improvements, especially in urban areas; develop a plan for the decarbonisation of transport; start considering an emission trading system for road traffic and so forth.

Table 2 Countries, Regions, and Cities that Have Made 2050 Net-Zero Declarations

Countries	Regions	Cities
Europe: Norway, Sweden, UK, France, Switzerland, Denmark, Germany, EU28, Ireland, the Netherlands, Finland, Iceland, Portugal **Oceania**: New Zealand, Fiji, the Marshall Islands **Asia**: Bhutan **South America**: Chile, Uruguay **Central America**: Costa Rica	**USA**: Hawaii, California, New York **Canada**: Victoria **Europe**: Scotland, Catalonia **Australia**: Australian Capital Territory, Queensland, South Australia, New South Wales, Tasmania	**Europe**: Barcelona, Paris, Reykjavik, London, the Hague, Copenhagen, Oslo, Stockholm, Helsinki **North America**: Boston, Indianapolis, San Francisco, Seattle, Washington DC, New York **Australia**: Canberra, Melbourne, Sydney **Africa**: Cape Town **Japan**: Figure 2

Reference: IGES, based on the UNEP GAP Report [23]

Box 2 Local Governments' Net-Zero Declarations[13]

By mid-2019, the Cities of Kyoto, Yokohama and Tokyo took the lead ahead of the rest of Japan by declaring a commitment to net-zero. Yokohama declared its commitment to achieve net-zero GHG emissions during the latter half of the 21st century ("Zero Carbon Yokohama") while Tokyo declared it will achieve net-zero CO_2 emissions by 2050 ("Zero Emission Tokyo Strategy"). Many local governments in Japan have committed to taking action to achieve net-zero emissions by 2050 (Figure 2).

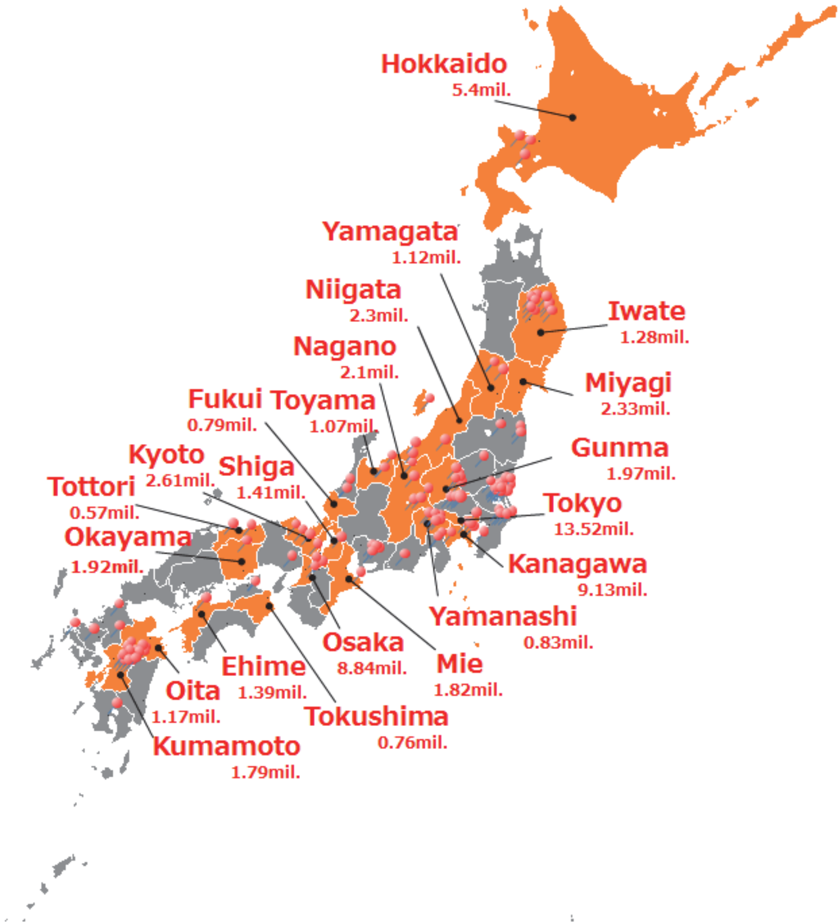


Figure 2 Local Governments that Have Declared to Achieve Net-Zero CO_2 Emissions by 2050
Reference: The Ministry of the Environment, Government of Japan[24]

[13] Apart from the Net-Zero Declaration, local governments in Japan and abroad are increasingly making "Climate Emergency Declarations". As of 20 January 2020, seven local governments in Japan have declared climate emergencies. The Japanese local governments' increasing awareness of the climate crisis is thought to help promote Net-Zero Declarations among them as well [139].

To offset the CO_2 or CFCs released during manufacturing, as well as methane and other gases from the agricultural sector, methods such as afforestation and reforestation, as well as negative emission technology (NET) including bio-energy with carbon capture and storage (BECCS) as well as direct air capture and storage (DACS) technology must be employed. Here, major cities can work with rural localities to take advantage of unused land due to depopulation. In this way, achieving net-zero will require reducing energy demand, scaling up renewable energy, and adopting, to the largest extent possible, economically reasonable NET options. The success of net-zero declarations in major cities will depend on achieving negative emissions in rural localities. For example, Yokohama City has net positive emissions, but by cooperating with localities in Northeast Japan to increase renewable energy supply, these localities can achieve net negative emissions. In turn, this consortium of localities can achieve net-zero emissions together. These collaborative efforts form a basis for the concept of 'regional circulating and ecological spheres' by capitalising on the local resources specific to each region, creating independent and decentralised societies, while complementing and supporting regional resources with neighbouring localities [25].

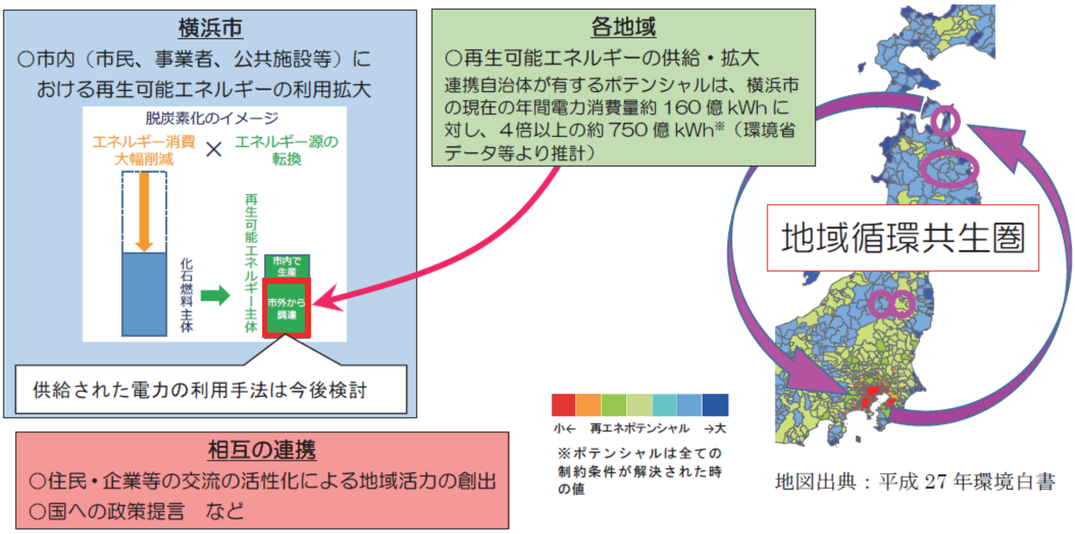


Figure 3 Collaborative Efforts with Other Regions to Realise "Zero Carbon Yokohama"
Reference: Climate Change Policy Headquarters, City of Yokohama[25]

Net-Zero Societies — Social Change and the Driving Forces

A net-zero world is now becoming a global objective, and presumably it will be very different from today's society, in areas such as people's lifestyles and workstyles, industry, urban structure, energy use and supply, and science and technology. Awareness of the climate crisis is thought to be the most important driving force for transitioning to a net-zero world. However, given the particular complexity of social changes in future, it is important to consider their impact in areas other than climate change response. Figure 4 illustrates the linkages between social changes and energy demand that are likely to emerge by 2050, and their driving forces, as predicted in this report. For Japan, the most important issues and driving forces through the middle of the 21st century include: rapid population decline; deepening awareness of the climate crisis and scaling-up of responses; the need to build a circular society to address waste and resource issues; innovations in science and technology; international commerce; and the adoption of new practices and norms. These forces will likely cause major social changes, such as depopulation, declining birth rates, an ageing population, decarbonisation and improvements in resilience, the formation of a circular society, and digitalisation through AI and IoT. Presumably, they will drive fundamental transformations in the socio-economic system's production and consumption processes, such as regional decentralisation, centralisation of urban functions, promotion of the 3Rs (Reduce, Reuse, Recycle), the sharing economy, and customisation and demand flow production. Any fluctuation in energy demand as a result of these complex trends will no doubt influence the degree of difficulty in achieving a net-zero world.

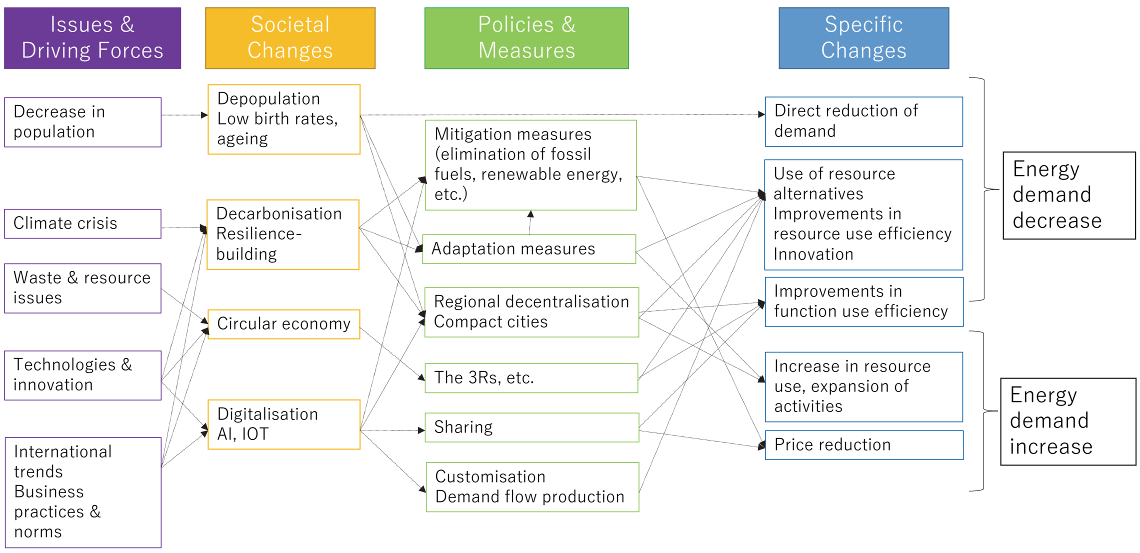


Figure 4 The Relationship Between Driving Forces of Social Change and Energy Demand

Keeping such complex processes in mind, this report will use a scenario analysis approach (as described later) to show two scenarios of the net-zero world. Of course, it is not possible to account for all future events, and the discussion will focus on the major issues which can be identified as of 2019. It goes without saying that the global challenges associated with climate change require international measures and that geopolitical changes result from nationalist ideology (including regional fragmentation and trade friction) are important points to consider; however, these are beyond the scope of this report, since its analysis focuses on Japan.[14] There are various pathways toward net-zero, and it is important to note that the scenario described in this report is just one example giving a snapshot of such a society around 2050. Further analyses will be conducted with respect to a concrete transition pathway toward such a world.

Box 3 Are we nearing the end of our fossil fuel civilisation?

Jeremy Rifkin, famous for works such as "The Zero Marginal Cost Society", mentioned in his recent work "The Green New Deal" that numerous research organisations linked to major industries have made predictions in the last few years that the "fossil fuel civilisation" will collapse between 2023 and 2030. What is important here is that these movements are market-driven and that "any national government that does not heed the movement of the markets will pay a price". Particularly in the United States, the world's top oil-producing country, major sectors such as IT, energy/electricity, transport and logistics, as well as the building sector, are all reducing their dependence on fossil fuels and starting to switch to cheaper green energy. With the cost of solar and wind power plummeting, the impact of peak oil demand (where demand for oil peaks before supply), and the vast amount of stranded assets, such market forces make this movement toward green energy inevitable. However, will Japan be fully prepared for such a large, global market-driven wave of change?

[14] For example, among the five SSP Scenarios (SSP1-5), SSP3 assumes that regions are divided [54].

Chapter 1: Quantifying a Society with Net-Zero GHG Emissions

Development of two scenarios for a Net-Zero World

Amid warnings of a global climate crisis, and concerns about international business practices and norms related to climate change issues, some countries, especially in Europe, have begun to pivot towards long-term strategies for a society with net-zero GHG emissions. At the same time, the rapid evolution in information and communications technology has had a major impact on both the real economy and the financial economy. This is likely to affect all entities on a global level, changing the basic ways in which we live and work. In other words, we are entering an era necessitating a transformation of various elements such as existing social systems, economic structures and energy systems [24]. We must therefore consider the net-zero world in accordance with these transitions. On the other hand, building such a net-zero world is not easy. In particular, there may be those advocating a cautious approach-who oppose setting a net-zero goal (Chapter 3), expressing concerns about drastic social transformation, and that efforts toward net-zero will sacrifice economic growth. As a result, those holding these opinions may only accept changes via technological innovation, and if existing social systems, economic structures, and physical infrastructure are not altered significantly.

Against this backdrop, and in light of diverse opinions on what the economy and society will look like in the future, this report identifies a range of possibilities. It does so by pointing out domestic and international issues that are the driving forces for social change, and referring to strategies and roadmaps put forward by governments and a range of organisations [27,28,37–46,29,47,30–36]. This report summarises how these issues bring about social change and affect resource and energy demands. While the future might entail various possibilities, this report describes two distinctive scenarios. These are (1) a lock-in scenario that envisions technological progress in a society in which existing systems and institutions are not changed significantly, and the current situation is maintained, and (2) a transition scenario that envisions technological development and involves a transformation of various social elements. In other words, **<u>a lock-in scenario is one with insignificant changes in society, and a transition scenario is one that transforms important social elements such as existing social systems, economic structures, and infrastructure in response to international trends, domestic social issues, and technological progress.</u>** Based on these two scenarios, this report will carry out a quantitative analysis of a net-zero world.

Table 3 Social Assumptions used by the Lock-in Scenario and Transition Scenario

Viewpoint of Analysis		Lock-in Scenario	Transition Scenario
People's way of thinking and acting	Sense of value	Value in possession	Value in use
	Economy	Economic rationality	Growth of preference for economic rationality, environmental rationality, and quality of life
	Resilience	Increased awareness of safety and disaster prevention	Increased awareness of safety and disaster prevention, visualisation and internalisation of social cost of carbon (SCC)
Cities and Regions	Urban and regional land use	Sprawl, and no change in urban land use	Centralisation of urban functions, selection and concentration of infrastructure (simultaneous progress of decarbonisation and improvement of resilience), and utilisation of idle land (renewable energy, afforestation)
	Transportation, Mobility	Automation, partial electrification	Promotion of electrification, automation, and use of public transportation
	Municipalities	No expansion of net-zero cities	Expansion of net-zero cities, collaboration of urban and suburban cities
	Energy use	Dissemination of ZEH and ZEB (Zero Energy House/ Building) in some houses, office buildings	More than half of the people live in ZEH, promotion of ZEB on the occasions such as rebuilding office buildings, electrification of energy required for air conditioning and heating, and district heating by utilising waste heat in cold regions.
Life (Lifestyle, work style)	Holiday, free time	Maintaining current holiday and free time	Increased holiday and free time, investment in self-fulfilment
	Consumption	Possession of products	Consumption of function and services, the sharing economy (cars, durable goods)
	Purchases	Efficient purchasing through digitalisation (e.g. AI, IoT)	Efficient purchasing through digitalisation (e.g. AI, IoT), health consciousness, visualisation and internalisation of SCC
	Labour	Online meetings to some extent	Progress in remote working and online meeting
	Production and disposal (waste, resource issues)	Mass production/mass disposal, current resource circulation	Creation of circular society, customising demand flow production (e.g. introduction of 3D printer)
	Energy use	Living as energy consumers in society where energy-related problems are dealt with on the supply side	Living as energy prosumers in harmony with fluctuation of renewable energy by applying demand-response related technology
Industry	Manufacturing industry	Efficient production method and process, introduction of low carbon technology, and electrification	Efficient production method and process, introduction of decarbonisation technology (replacement of existing technology), and promotion of electrification
	Energy use	Dependence on fossil fuels, progress on energy efficiency due to technological advancement	Progress on energy efficiency due to mainly renewable energy, technological advancement and electrification
	Agriculture, forestry, and fisheries	Efficient management by digitalisation (e.g. AI, IoT)	Efficient management by digitalisation (e.g. AI, IoT), electrification and fuel cell development of agricultural machinery and fishing boats, provision of service of agriculture-and-forestry experience, provision of new material and material for electricity generation and heating equipment

Adaptation (Improvement of resilience)	Adaptation measure	Mainly defending from natural disasters	Minimisation of damage, transitional adaptation
	Integration of mitigation and adaptation	Partial synergy with mitigation	Synergy with mitigation, simultaneous progress on decarbonisation of infrastructure and improvement of resilience
	International trends, business practices and norms	Reaching the limit of TCFD response	Major change in cooperative behaviour due to legalisation of TCFD and behaviour with the internalisation of SCC
Electricity	Power supply composition	Continuation of use of fossil fuels using CCS	Variety of renewable energy become the main source
	Power system/transmission grid	Centralised power supply/existing power system	Expansion of decentralised power supply/transmission network, demand response, P2P transaction, practical use of VPP

As shown in Figure 4 on page 26 (the relationship between driving forces of social change and energy demand), the characteristics of social change in the IGES transition scenario are based on the following assumptions: depopulation and declining birth rate and ageing population, decarbonisation, improvement of resilience, sound material-cycle society and digitalisation, among others. The international community has pointed out the need for a broad transformation of social systems to achieve the sustainable development goals (SDGs), and many organisations have proposed definitions about what this means. Although future time scales are still not very clear, for the sake of comparison, Table 4 shows IGES' analysis of the components of social transformation both globally and in Japan, as reported by other research organisations.

One common point of the analyses carried out by other organisations (IIASA, SDSN, WBA, GSDR) and IGES is the importance placed on decarbonisation and digitalisation. The elements that are not in the IGES scenario but are in the reports by other organisations include: human well-being and welfare such as gender, education, inequality and health; global resource utilisation such as food and water, and; factors related to the quality of economy such as a fair economy. On the other hand, the elements that are not included by other organisations but are included in the IGES scenario are: improvement of resilience and centralisation of urban functions; the sharing economy; and demand flow technology (Table 4). The main features of the IGES scenarios are the consolidation of urban functions driven by depopulation, declining birth rate and ageing population, and greater resilience in response to severe weather-related disasters, if the sharing economy, customisation, and demand flow production are included in digitalisation.

Table 4 Components of Social Transformation Emphasised by Various Organisations

IIASA	SDSN	WBA	GSDR2019	IGES (Japan)
• Human capacity and demographics • Consumption and production • Decarbonisation and energy • Food/ biosphere/ water • Smart cities • Digital revolution	• Education/ gender/ inequality • Health/ wellbeing/ demography • Energy decarbonisation / sustainable industry • Sustainable food, land, water, and ocean • Sustainable city and community • Digital revolution for sustainable development	• Agriculture and food • Decarbonisation and energy • Circular (transformation) • Digital (transformation) • Urban (transformation) • Social (transformation)	• Human well-being and capabilities • Sustainability and just economies • Food systems and nutrition patterns • Energy decarbonisation / universal access • Urban and peri-urban development • Global environmental commons	• Depopulation/ low birth rate and ageing population • Centralisation of urban function • Decarbonisation • Resilience improvement • Sound material-cycle society • Digitalisation (AI, IoT)

Note: GSDR2019 refers to the report. Social transformation assumed by IGES is limited to the Japanese society in Japan in the context of this report.

Source: Authors' formulation, based on the WBCSD document "VISION 2050 Refresh Workstream: Exploring Systems Transformation"

As shown in Box 4, the rate of economic growth is a critical factor in scenario analysis because it fundamentally influences the sustainability of living and society. It is also a way of measuring the volume of economic activity. In Japan, the annual average GDP growth rate during the 10 years from 2005 to 2015 was 0.5%, and average GDP growth per capita was also 0.5% [48] . Moreover, it has been recognised that the concept of "infinite expansion/growth", which is often regarded as the basis of capitalism, is reaching its limits when viewed from the perspectives of materialism and finite natural resources, as well as a psychological aspect such as "happiness". Thus, the importance of ideas such as de-growth and a creative, steady-state economy [49] have been recognised in recent years [50,51]. In light of this analysis, the main purpose of this report is to compare the status of GHG emissions and energy use in a net-zero society under the lock-in scenario and the transition scenario. To do this, the analysis assumes that the economy as a whole is stable (GDP per capita grows 0.6% annually, and Japan's total GDP remains at the 2015 level) as explained in Chapter 1.

Box 4 The Dilemma of Growth, Challenges for Sustainable Development

The "dilemma of growth" was addressed by Tim Jackson in his popular book "Prosperity Without Growth", published in 2009. It suggests that economic growth pursued by developed countries in the past may be not sustainable, considering environmental limitations such as planetary boundaries. It also highlights the dilemma that halting economic growth, or "de-growth", may destabilise social and economic systems. A politically attractive solution to the dilemma of growth confronted by developed countries would be the decoupling of resource use and environmental burdens from growth, by significantly improving resource and environmental efficiencies through technological innovation. However, given the role of GDP growth in the current economic and social systems, it would be difficult to achieve sustainable production and consumption solely by improving efficiency. Consumption in developed countries has reached unsustainable levels, yet those countries still believe that they need to increase GDP growth by encouraging consumption using advertising and other means. This is because key systems such as those for finance, pension or employment are designed to depend on GDP growth. To avoid recession and other system failures, "sufficiently strong" GDP growth is necessary. Under these conditions, more rapid GDP growth is a social necessity, and is seen as a "good thing". Therefore, there is a strong incentive to increase GDP growth as much as possible. Under systems that depend on GDP growth, the benefits of efficiency improvement may be used for more rapid GDP growth rather than a reduction in the absolute amount of resource utilisation and environmental load. The rebound effect may be an inevitable consequence of GDP growth-dependent societies. Jackson states that prosperity without growth is no longer a utopian fantasy for the economies of developed countries. It is financially and ecological essential. Once we have transitioned to a system that does not depend on growth, then decoupling through technological innovation can have a more positive meaning if we are questioning sustainable development in terms of how to live abundantly within planetary boundaries. Rather than using technological innovation to alleviate environmental constraints, it can be used to expand the frontier within those constraints. This approach provides not only the right result but also incentives for technological innovation. People are more likely to come up with imaginative ideas when they believe that innovation will improve their quality of life, rather than when they feel that insufficient innovation would mean that planetary boundaries are crossed.

Source：Authors based on the commentary on "Bankrupting Nature: Denying Our Planetary Boundaries" by Anders Wijkman and Johan Rockström [52]

Estimating GHG Emissions for Each Scenario

Many studies carried out in Japan and other countries have analysed multiple scenarios for what society might look like given an uncertaion future. For GHG mitigation scenarios, the National Institute for Environmental Studies (NIES) developed the Japanese low-carbon scenario, based on the Special Report on Emission Scenarios (SRES) [53] (IPCC emission scenario) and shared socio-economic pathways (SSP) [54,55], which became the framework for a joint study with the IPCC. The SRES broadly classifies the possibility of future socio-economic development into four categories, depending on whether they are economic-oriented, environmentally-oriented, earth-oriented or region-oriented. SSP places the difficulty of mitigation and adaptation on the vertical axis and horizontal axis respectively, and classifies them into five social scenarios (SSP1-SSP5) including a moderate scenario. Conversely, the LED scenario [56] quoted in the IPCC Special Report at 1.5°C, presented one scenario in which global energy demand is significantly reduced by the five drivers of social change (quality of life, urbanisation, innovative energy services, end-user roles, and information innovation).

For Japan, a study by the National Institute for Environmental Studies (NIES), and a report by the Global Environment Subcommittee of the Central Environment Council, Japan include scenarios for a dynamic and comfortable society [57,58], with measures after 2013 analysing five social scenarios [59] derived from three aims — economic growth, independence, and leisure. The Japan Center for Economic Research analysed Japan's GHG emission reduction cases in 2050 after the transition to the digital economy [60]. As described above, scenario analysis basically presents a wide range of scenarios to include the most conceivable number of future possibilities. Thus, Chapter 1 provides an analysis of the two social scenarios that would achieve a net-zero world.

Changes in the amount of activity, changes in energy use, and the level of progress being made in decarbonisation of fuel are all analysed by revewing a range of literature and conducting expert interviews, looking into the household, commercial, transportation (land passenger transport, land freight, shipping, aviation), and industrial (eight sub-categories: steel, glass and other ceramics, petrochemical products, ammonia production, soda product production, other petroleum and coal products, pulp paper, and other manufacturing) sectors. GHG emissions other than CO_2 are also taken into account in both scenarios. Items to be considered on the demand side include demographics, centralisation of urban functions, changes in lifestyles and work styles, the spread of AI and IoT, development of a sound material-cycle society, and trends in international economies and norms. We quantified how much the demand for energy and materials will change in line with the progress of suggested social and technological circumstances. Decarbonisation technology in each sector of industry and transportation are identified based on various documents, including reports by various organisations and European institutions. We applied the assumption that each sector can use CCS to the maximum extent for the remaining CO_2 emissions if CCS is applicable for that sector, such as large-scale fixed emission sources within industries. For CO_2 emissions from small-scale emission sources, such as the the transportation and livelihood sectors, we assumed the usage of Direct Air Capture and Storage (DACS) that absorbs emission-equivalent CO_2 from the atmosphere with Direct Air Capture (DAC) [61] and injects the absorbed CO_2 with CCS as a negative emission technology.

The structure of any future power supply could change significantly due to possible further technological advances related to renewable energy and battery storage, commercialisation of offshore wind power, transmission and distribution network development, demand response, and VPP technology. A detailed analysis on this is beyond the scope of this report since power systems analysis that includes balancing between electricity supply and demand is very complex, and so it should be dealt with using specific power system models in another report. For the lock-in scenario, we simply extended the figures derived from the energy mix under the 2030 target set in Japan's NDC [62] in 2015, to set the ratio of power supply for the lock-in scenario as: 50% from non-fossil fuel power sources; 25% from high-efficiency gas thermal power with CCS; and 25% from high-efficiency coal-fired power with CCS. In the transition scenario, we assumed that all energy supply will come from non-fossil power sources, and that there will be technological advancements in renewable energy [63] .

We evaluated the feasibility and sustainability of each scenario by comparing the results of analysis with a focus on renewable energy usage, CCS usage, and imported energy. The amount of CCS usage was compared with the range of CO_2 storage potential in Japan to quantify how long a net-zero world using CCS could be sustained. Renewable energy was compared with the amount of energy required to achieve the status of a net zero society depicted in this report and the amount of renewable energy available in Japan (which is different from total renewable potential, without considering the socio-economic aspects). The amount of imported energy was estimated based on the amount of fossil fuel use in 2015 and projected for 2050.

Concept of GHG Emission Estimation and Data

In this report, the amount of GHG emissions for a net-zero world is examined using the equation below (1). Here, *GHG* represents GHG emissions, *pop* is population, *GDP* is the real GDP in 2015, $activity_i$ is the amount of activity by sector (e.g. production amount in the industry sector, amount of travel in the transportation sector, energy demand in the commercial sector). The sectors included in the analysis are: households; businesses; transportation (passengers by land, cargo by land, shipping, and aviation); and industry (eight types: steel, glass and other ceramics, petrochemical products, ammonia production, soda product production, other petroleum products, pulp paper, and other manufacturing). TFC_i shows the final energy consumption in each sector, and GHG_i shows the amount of GHG emissions in each sector.

$$\mathrm{GHG} = \mathrm{pop} \cdot \frac{GDP}{pop} \cdot \frac{1}{GDP} \cdot \sum(activity_i \cdot \frac{TFC_i}{activity_i} \cdot \frac{GHG_i}{TFC_i}) \quad \text{(Equation 1)}$$

Figure 5 shows the process for calculating GHG emissions, identifying changes in the level of economic activity in each sector. The first step is to set the amount of activity in the household, business, and transportation sectors according to GDP assumptions and progress of social changes specified in each scenario. Based on this, any changes in energy and material usage are estimated (the actual values of energy usage and material usage in 2015 are shown in the reference material). The amounts of agricultural/industrial production are estimated according to the estimated material usage in households, businesses, and transportation. The amounts of GHG emissions and energy-derived CO_2 emissions are calculated by estimating the amount of energy and material required to satisfy those production amounts.

Based on the comprehensive energy balance data and statistics published by the Agency for Natural Resources and Energy in Japan [64] , this report estimates the energy use in the net-zero society, considering the changes in material usage and deployment of decarbonised technology in all the sectors.

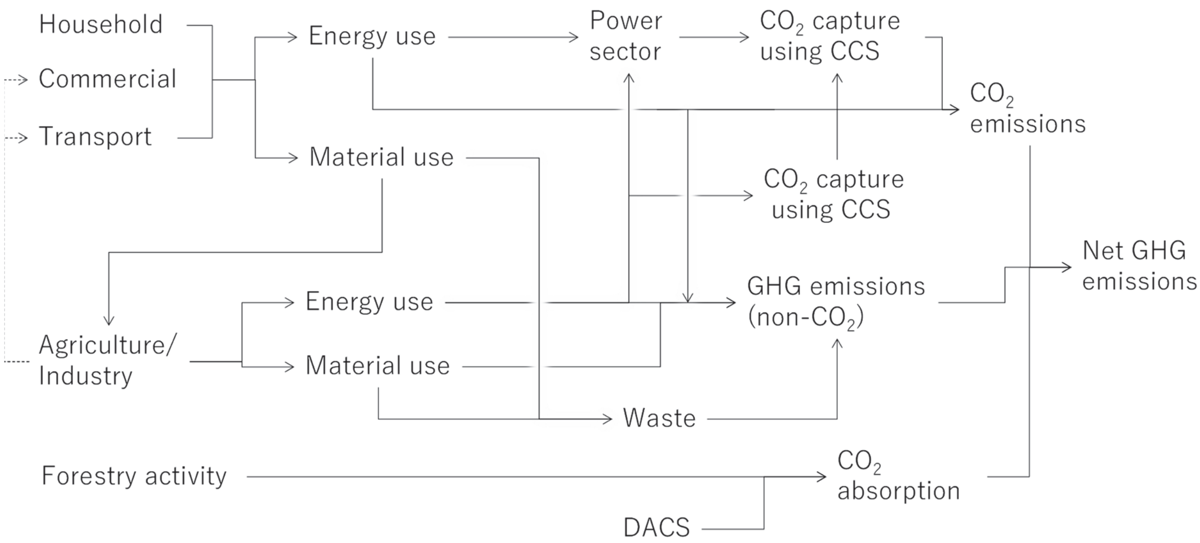


Figure 5 Approach for Estimation of GHG Emissions

Note: Material use in the industrial sector includes DAC technology that captures and uses atmospheric CO_2.

Result of Estimation

Figure 6 shows the amount of GHG emissions for each of the two net-zero world scenarios estimated in this report. The net-zero GHG emissions in 2017 were 1,236 $MtCO_2$, and this includes CO_2 emissions of 1,190 $MtCO_2$, non-CO_2 emissions such as methane, N_2O, and alternative CFCs, of 102 $MtCO_2$, as well as offsets by forest sinks of 56 $MtCO_2$.

In the lock-in scenario, the gross GHG emissions are 970 $MtCO_2$, of which 555 $MtCO_2$ is captured and stored underground using CCS technology. Non-CO_2 emissions are 56 $MtCO_2$, forest sinks are 39 $MtCO_2$, and reductions made overseas through the JCM are 5 $MtCO_2$. This will result in net GHG emissions of 372 $MtCO_2$, and net-zero is achieved by collecting this same amount from the atmosphere using DACS technology, and storing it underground. As described, under the lock-in scenario gross CO_2 emissions would fall compared to 2017 but still remain high. Thus, it is shown that a net-zero world can be largely achieved by using CCS and DACS.

In the transition scenario, the gross CO_2 emissions and non-CO_2 emissions are smaller than those in the lock-in scenario due to changes in material usage, energy usage and fossil fuel. As a result, gross GHG emissions in the transition scenario are 147 $MtCO_2$, of which 68 $MtCO_2$ are captured and stored underground by CCS technology. Non-CO_2 emissions are 30$MtCO_2$, forest sinks are 41 $MtCO_2$, and reductions made overseas using the JCM are 5 $MtCO_2$. This would result in net GHG emissions of 33 $MtCO_2$, but net-zero could be achieved by absorbing the same amount of CO_2 from the atmosphere using DACS technology and storing it underground. Thus, it is suggested that the use of CCS and DACS could be significantly reduced in the transition scenario.

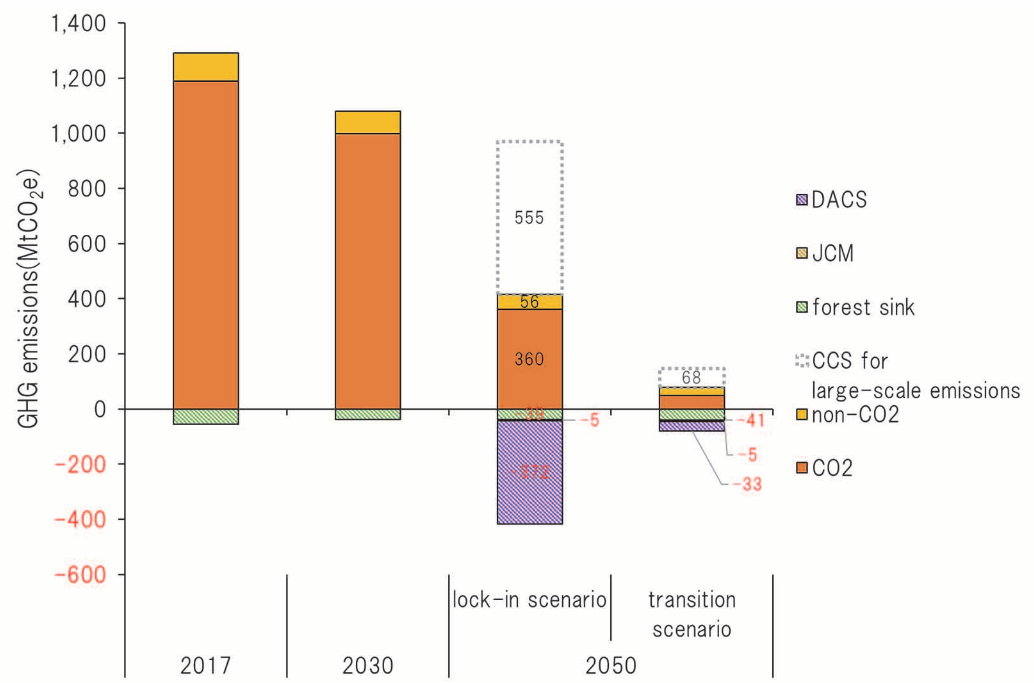


Figure 6 Structure of GHG Emissions in a Net-zero World

Figure 7 shows the final energy consumption for each scenario, and therefore the changes in energy use. In the lock-in scenario, energy consumption exceeds 10 EJ, the consumption structure that uses large amounts of energy persists, and in particular, the use of fossil fuel continues. In the transition scenario, the final energy consumption declines sharply to 62% of that in 2015. This is because energy demand is decreasing due to changes in material usage, optimising energy efficiency, and promoting electrification in all sectors.

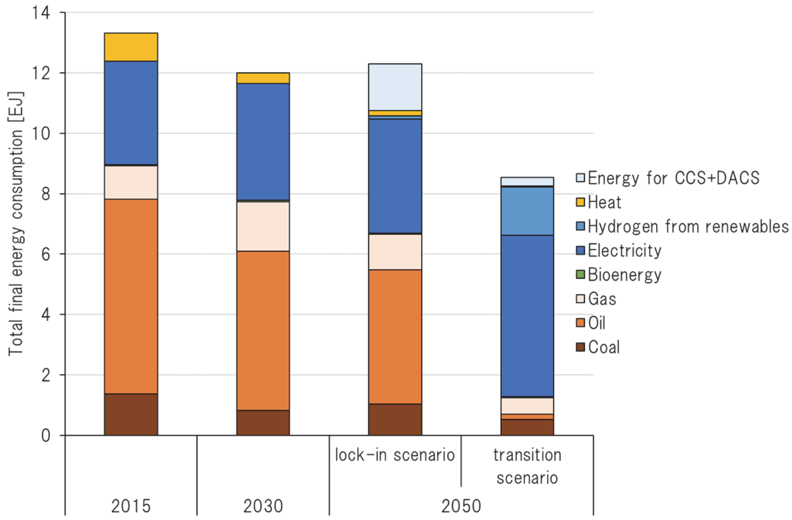


Figure 7 Total Final Energy Consumption by Scenario

Note: Energy used for the DAC in the chemical industry is included in electricity.

Furthermore, the amounts of final energy consumption by sector and by scenario are shown in Figure 8, 9 and 10. In 2015, electric power accounted for 50% of final energy consumption in the household and business (corporate / enterprise) sectors. Consumption of gasoline and diesel was the main source in the transportation sector. In manufacturing, the chemical and steel industries were major energy consumers. The chemical industry, including petrochemicals, used 1.5 EJ or more of petroleum and petroleum products. This is because petroleum and petroleum products are used as material to produce plastics, synthetic fibres, synthetic rubbers, and paints. In the steel industry, a large amount of coal is used in the production process of iron when iron ore is reduced to pig iron. The machine manufacturing industry consumes the third largest amount of energy in the manufacturing sector, but as of 2015, 70% of that energy was from electricity. Ceramics (e.g. cement, glass products) is also a fossil fuel-intensive industry: coal and coal products account for 40%, oil and petroleum products for more than 20%, and gas for less than 10% of the industry's total energy consumption.

In the lock-in scenario, decarbonisation of energy hardly makes any progress, as dependence on petroleum resources continues in the transportation and chemical sectors, including the petrochemical industry, as well as in the commercial and household sectors. In the lock-in scenario, energy use relies on fossil fuels, and CO_2 emitted from fossil fuels is mainly captured by CCS in the industrial sector. There are some CO_2 emissions that cannot be captured by CCS, including those from the use of petrochemical products, non-energy-intensive consuming industries, as well as the business, household, and transportation sectors, so reducing such emissions relies on negative emission technologies such as DACS to capture CO_2 from the atmosphere. On the other hand, in the transition scenario, non-fossil fuel power sources, including renewable energy, will be the major energy source. Decarbonisation of energy will be achieved even in energy-intensive industries like steel and chemicals, as progress is made in the use of hydrogen derived from renewable energy, and in electrification of the industrial, transportation, and household sectors.

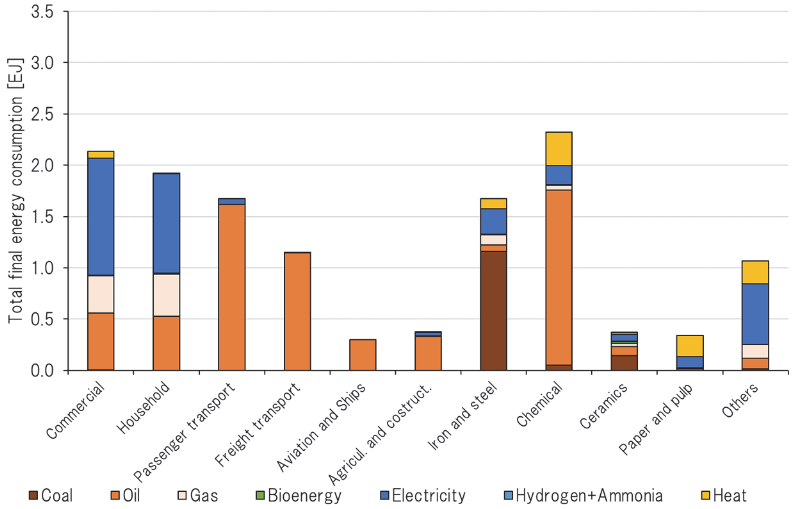


Figure 8 Final Energy Consumption by Sector (2015)

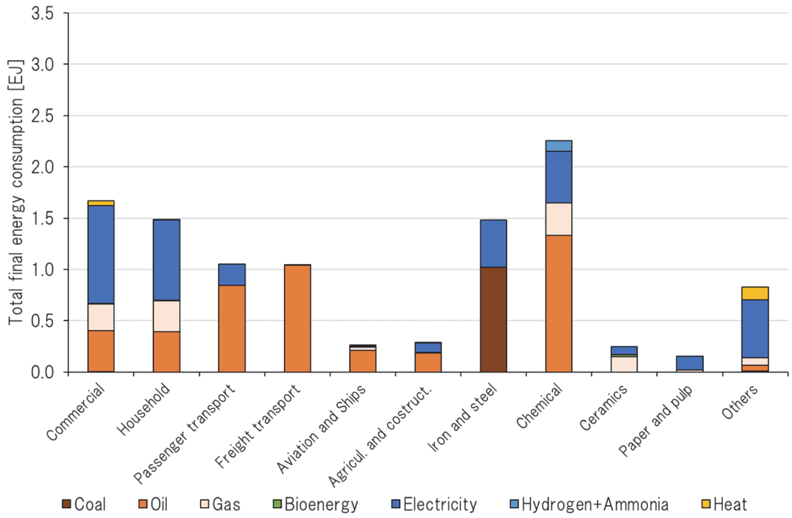


Figure 9 Final Energy Consumption by Sector (Lock-in Scenario 2050)

Note: Energy for CCS+DACS by sector is not estimated.

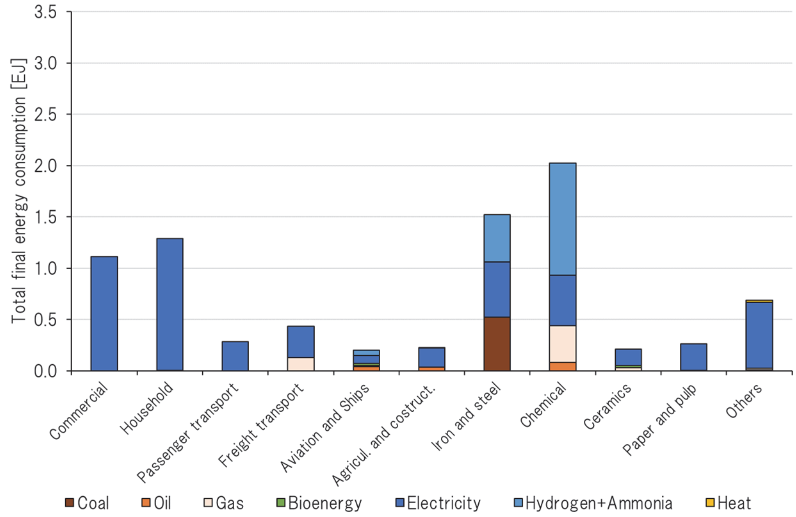
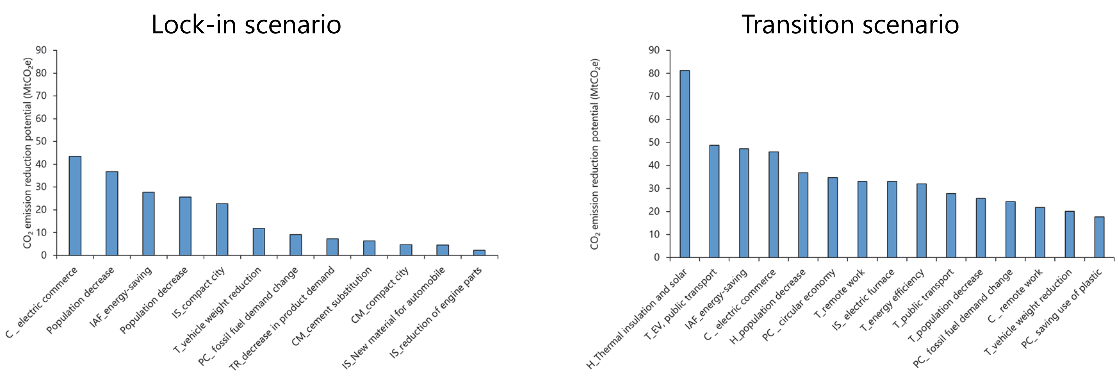


Figure 10 Final Energy Consumption by Scenario and by Sector (Transition Scenario 2050)
Note: Energy for CCS+DACS by sector is not estimated.

Figure 11 shows the amount of CO_2 reduction caused by social changes in each scenario, due to changes in lifestyles and the use of materials derived from a sound material-cycle society. In the lock-in scenario, in addition to climate change countermeasures such as energy-saving, there is a major reduction in emissions resulting from social changes such as online sales, centralisation of urban functions, and more lightweight automobiles (passenger transportation on land). In the transition scenario there are a number of additional social changes that make an impact on emission reductions, such as the spread of EVs (passenger cars and buses), online sales, recycling technology (formulation of sound material-cycle society), use of electric arc furnaces, and remote work, in addition to heat insulation/solar power in the household sector and energy-saving (other industries). Thus, the "CO_2 reduction potential" shown on the vertical axis is generally estimated to be larger in the transition scenario than in the lock-in scenario.



H: Household, C: Commercial, T: Transport, IAF: Other industrial including agriculture, forestry and fisheries, IS: Iron and Steel, PC: Petrochemicals, CM: cement
Note: If the CO_2 reductions by each change are added, overlap will occur, so it will not be equal to the sum of reductions in all sectors.

Figure 11 Amount of CO_2 Reduction due to Social Changes by Scenario

Discussion

This section discusses the feasibility of the lock-in and transition scenarios in terms of potential availability of renewable energy, the amount of domestic CO_2 storage capacity and the volume of fossil fuel imports by Japan.

Figure 12 shows a comparison between the electricity generation in 2050 for each scenario and the technological and economic availability of renewable energy. This report classifies the techno-economic availability of renewable energy into three cases: “a”, “b”, and “c”. The availability of renewable energy "a" is estimated based on MOEJ [65], ANRE [66] and NPU [67]. The techno-economic availability of renewable energy "b" is based on MOEJ [68] and JST [69]. The techno-economic availability of renewable energy "b+" assumes double the amount of solar power compared to “b”, considering the fact that “solar modules with over 50% conversion efficiency would be available by 2040” [70]. The techno-economic availability of renewable energy “c” is developed based on the JST report [71], and the availability of solar power in “c” is higher than those in “a” or “b”. For all the cases of techno-economic availability of renewable energy, the amount of off-shore wind power refers to MOEJ [72].

In the lock-in scenario, the estimated power demand exceeds the techno-economic availability of renewable energy "a". However, since the lock-in scenario assumes the use of fossil fuel power plants with CCS and nuclear power plants, the demand of renewable energy is considered to be less than the techno-economic availability of renewable energy "a".

In the transition scenario, the estimated power demand exceeds the techno-economic availability of renewable energy “a” and “b”. Therefore, if Japan aims for 100% renewable energy, further measures are needed, such as to improve the conversion efficiency of solar power modules, to install a solar power generation system on parking lots and roads, and to foster technological innovation related to offshore wind power, small wind power generation and tidal power generation. In addition, it would be necessary to promote efforts to implement technologies that have been considered unprofitable or that require the cooperation of residents. Also, another option could be to consider the idea of connecting the power grids of the countries in Northeast Asia (Russia, Mongolia, China, South Korea, Japan) to create an international power grid, which has been proposed by the international non-profit organisation, Global Energy Interconnection Development and Cooperation Organisation (GEIDCO) [73]. In particular, the South Gobi Desert of Mongolia has huge potential for solar and wind power generation [74]. In addition, an international power grid would contribute to the improvement of energy security in terms of reserve capacity, and would reduce the problem of intermittency of renewable energy output [75]. If Japan could invest in and implement these technologies and related infrastructure to promote the increased use of renewable energy, then there may be much more potentially available renewable energy than existing studies suggest.

Table 5 shows the domestic storage potential of CCS by geological characteristics and the number of available years in both lock-in and transition scenarios[15]. The potential amount estimated in this report is based on various reports that estimate the CCS potential using various geological structural parameters [76,77], conducted by research institutes including the Research Institute for Innovative Technology for the Earth (RITE). As with oil exploration and development, it should be noted that the results of the studies by RITE do not necessarily guarantee feasibility [78][16].

If Japan fully uses the domestic CO_2 storage required in the lock-in scenario every year, then CO_2 storage with the lowest uncertainty, using existing oil and gas fields, would run out in around four years, according to the assessment by RITE [79]. It should be noted that both the Nagaoka Project and Tomakomai Project, which currently have CCS demonstration projects in Japan, are conducted in areas where oil and gas fields are located [80,81]. Even if Japan uses domestic CO_2 storage in the anticline structure with medium uncertainty, which has been identified by basic drilling and basic exploration, it will run out in around 33 years (10 years with domestic storage potential confirmed by basic drilling, which surveys actual pile driving). Further, even if Japan assumes the CO_2 storage potential estimated in the MOEJ study conducted by Japanese think-tanks such as Mizuho Information & Research Institute, Inc., the National Institute of Advanced Industrial Science and Technology, and Chiyoda Corporation (hereinafter "think-tank assessment") [77], it will run out of domestic potential of "no distribution of subduction faults" in around 23 years, and run out of the potential of "small distribution of subduction faults" in around 57 years. Therefore, although it may be possible to temporarily achieve a net-zero world that envisions massive use of CCS, there remains the risk of a gap between the domestic CO_2 storage potential and the amount of CO_2 storage in the lock-in scenario. Thus, the net-zero world in the lock-in scenario may not be sustainable.

Figure 13 shows the fossil fuel imports for each scenario. While Japan imported 17 EJ of fossil fuel in 2017, the lock-in scenario and the transition scenarios project the need for 12 EJ and 1 EJ of fossil fuel in 2050, respectively. On a monetary basis, in 2015, Japan imported more than JPY 19 trillion of fossil fuels (JPY 8.9 trillion for crude oil, JPY 5.4 trillion for natural gas, JPY 2.8 trillion for coal, and JPY 2.1 trillion for petroleum products) [82].

In the lock-in scenario, the amount of fossil fuel required will be around 70% compared to the 2015 level, which can be calculated at JPY 13 trillion based on the current price. Thus, the lock-in scenario would carry substantial risks from the viewpoint of the trade balance and energy security. On the other hand, in the transition scenario, the use of fossil fuels will be reduced to 7% compared to the 2015

[15] A study suggests that the storage potential outside Japan is about the same as domestic volume [140]. However, it is not possible to directly compare the storage potential amounts because of differences in the estimation approach. Thus, this report does not include the storage potential outside Japan

[16] Against this background, the Japan Energy Economic Research Institute assumes that the domestic CO_2 storage capacity is approximately 3,000 $MtCO_2$[78].

level. The cost of fossil fuels imports is estimated to be about JPY 1.4 trillion, which implies that it will be possible for Japan to achieve huge savings on fossil fuel imports amounting to about JPY 17 trillion.

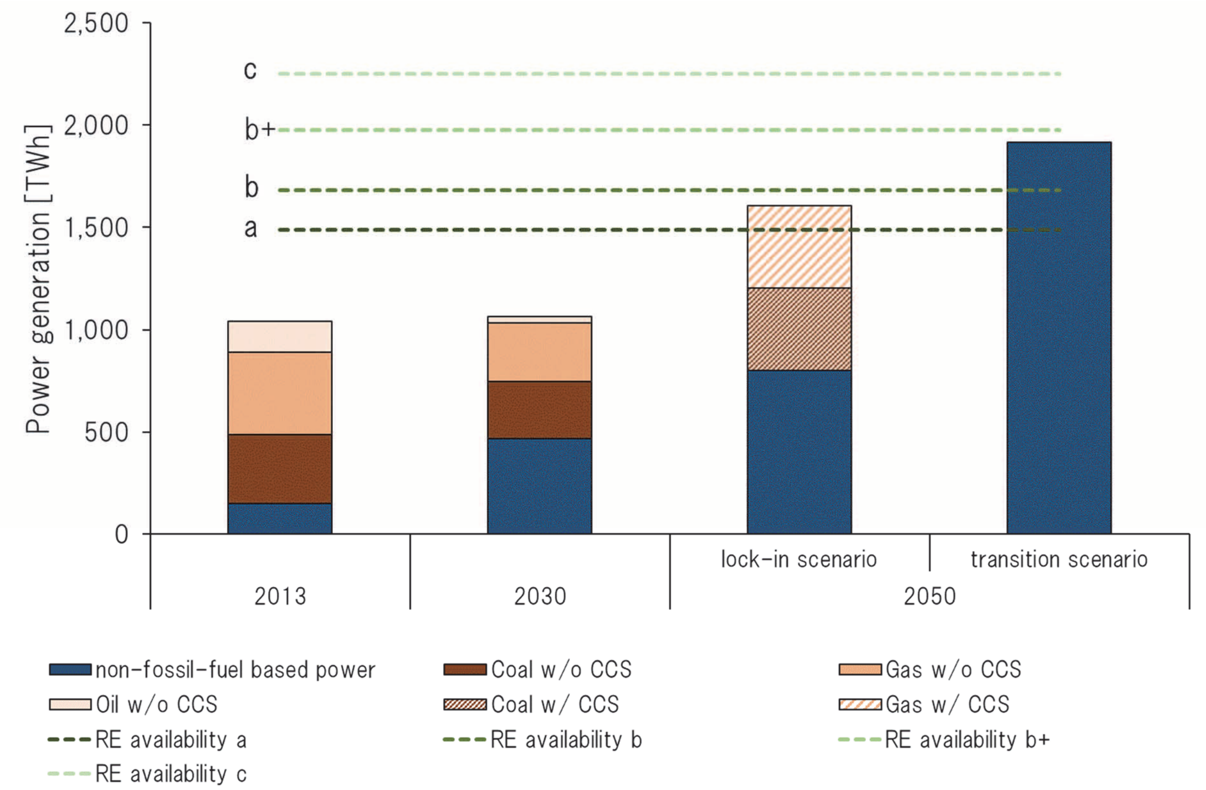


Figure 12 Comparison of the amount of electricity generation in each scenario and renewable energy potential

Table 5 Domestic CO_2 storage potential and number of available years for the potential in each scenario

Source	Domestic CO_2 storage potential by geological data and storage site characteristics	Domestic storage potential ($MtCO_2$)	Lock-in scenario	Transition scenario
RITE's assess-ment [79]	Storage in anticline structure identified as the existing oil and gas field	3,492	4 years	34 years
	Storage in anticline structure identified by oil foundation drilling survey	5,202	6 years	51 years
	Storage in anticline structure identified by oil foundation investigation	21,393	23 years	211 years
Think-Tanks assess-ment [77]	Storage in no distribution of subduction faults	21,301	23 years	210 years
	Storage in the small distribution of subduction faults	31,515	34 years	311 years
	Storage in the large distribution of subduction faults	27,813	30 years	274 years

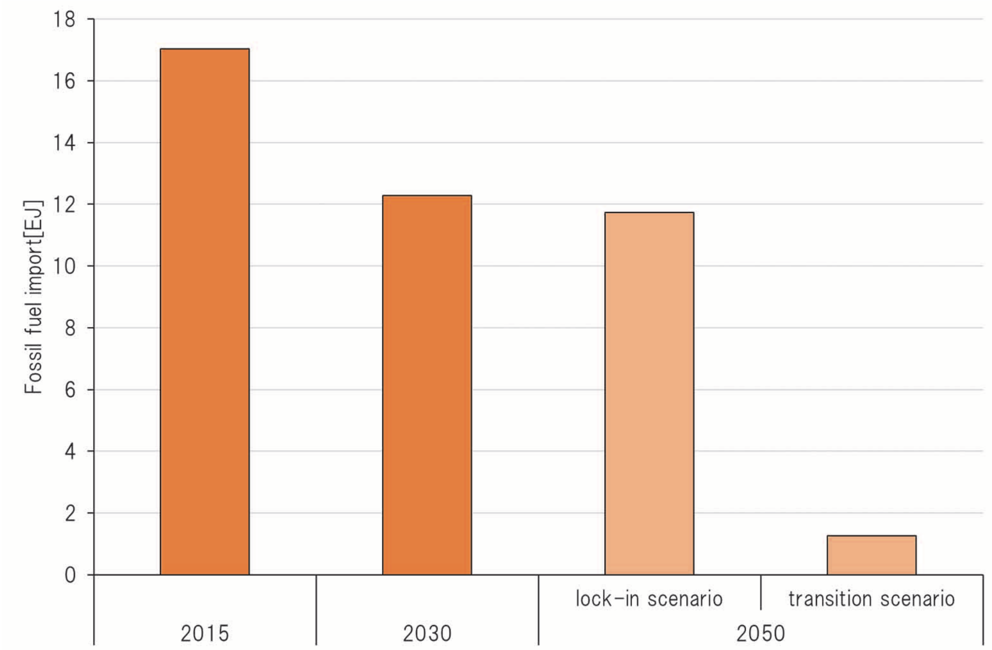


Figure 13 Amount of fossil fuel imports in each scenario

Chapter 2: Visions for a Net-Zero GHG Emission Society

In Chapter 1, the transition scenario demonstrated that a society can ensure energy security and significantly reduce or avoid related payments for energy imports since most of the energy required for living and industrial activities will be covered by domestic renewables. In addition, this scenario showed the advantages of CO_2 storage and low dependence on fossil fuels to avoid issues that could become major problems in the future. On the other hand, the transition scenario assumes that various changes would occur across all spheres in society, so it is not easy to accurately estimate their cumulative effect. Therefore, in order to understand these changes more clearly, Chapter 2 looks at society from the perspectives of cities and regions, daily life, and for industries, and considers any necessary adaptations, to help us understand what the year 2050 would look like under the transition scenario. Today's Japan faces a multitude of challenges including demographic issues like a declining birth rate and an ageing population, social welfare issues including pensions, labour issues such as long working hours and non-regular employment, inequity in society, as well as response to natural disasters. It can be assumed that people's ways of thinking and behaviour in society today would differ greatly in a net-zero world. Some of these aspects are described below.

Outline of visons for a Net-Zero GHG Emission Society

- Comprehensive progress is made in developing a wide range of net-zero infrastructure (such as both soft and hard energy paths for renewables, transportation including logistics, buildings, electronic communication networks and AI) so that renewable energy, transportation operated without using internal combustion engines, zero CO_2 emissions in manufacturing and construction, and AI are installed in every corner of society.
- With the increasing impact of climate change, the social cost of carbon (SCC) [2,3] is commonly recognised by the general public, and a corresponding carbon price is introduced (carbon pricing).
- Renewable energy is used to the maximum extent due to economic factors, such as price reductions due to the expansion of the global market (Figure 17), which overwhelmingly increases the competitiveness of renewables against fossil-fuel derived energy.
- Electric vehicles are introduced to the maximum extent possible, enabled by widespread development of the necessary relevant infrastructure by both the public and private sectors, as well as a decrease in battery-pack prices due to the expanding global market (Figure 18).
- There is progress in electrification in all sectors, which significantly contributes to improving energy efficiency. Typical technologies include the use of heat pumps for households, businesses, and industries that use low-temperature heat, and the use of electric motors in the transportation sector [83,84]. Use of renewable energy expands as electrification increases.

- The overall productivity of the manufacturing industry is enhanced. Efficiency throughout the supply chain is improved as the sound material-cycle society or circular economy progresses. There is no longer a large amount of unsold stock due to highly accurate marketing and detailed sales policies such as dynamic pricing, with progress made on optimisation of inventory management in terms of time and space.
- Divestments and issuance of green bonds are more common. In addition, international society reforms financial mechanisms to avoid funding activities that have a negative global impact.
- On the demand side, consumers are much more aware of environmental value (environmental rationality), rather than just prioritising low prices (economic rationality), and this shift in demand is promoted through marketing. This induces major changes in products and services, making them more sustainable.
- People shift their sense of value from “ownership value” to “functional value”, so there is a decrease in the resources and energy required to achieve the same level of value throughout society.
- Holidays and free time increase, so there is more time available for self-fulfilment.
- The value of time becomes more important. Time previously spent on housework and shopping is drastically reduced due to efficiency improvements using AI and IoT, or other alternatives such as robots. In addition, commuting time is slashed as working at home becomes the norm. Regarding mobility, transfers on public transport become more efficient, and waiting times are reduced. At the same time, the time required for transportation is considerably shortened as travellers are given information about the most suitable means and route.
- There is increased demand for high-quality spaces. Buildings have superior insulation, resulting in a quieter and more comfortable indoor environment. When travelling, importance is placed on qualities such as more space per traveller, comfort (a quiet, smooth ride), as well as a stable communication network. Travel time is utilised for work and hobbies. All forms of public transport ensure adequate seating as optimal.
- Weather forecasting and real-time information are accurately transmitted in a detailed web of information, infrastructure for disaster prevention is developed, and people can prepare for sudden changes in the weather, including reconsideration of transportation modes.
- Energy consumption associated with electronic computing is significantly reduced by using quantum computers [60].

Box 5 Use of Dispersed Energy Sources

To turn renewable energy into the main power source, it is necessary to introduce a large number of small-scale power sources such as solar panels. In this case, renewable energy is becoming more accessible and familiar, with solar panels placed around houses, and small and medium-sized hydroelectric power stations set up in nearby rivers. Thus, some of the electricity we consume comes from these solar panels or small and medium-sized hydroelectric stations. However, renewable energy supply in urban areas will not be enough to meet all power demand. Therefore, the existing power grid should be utilised wisely in order to make use of renewable energy generated from other regions. Renewable energy among dispersed power sources generates electricity at different times depending on weather conditions such as sunshine and wind. In order to use a large amount of renewable energy, it is necessary to manage the power flow second-by-second in an autonomous and flexible way, and a balance between power generation and consumption must be maintained throughout the entire power system. This can be achieved by using many small power stations and technologies such as storage batteries and virtual power plants (VPP), that collectively manage the power demand control system as if they were one power plant. As described, energy supply and demand, which are spatially and temporally uneven, are integrated by new technology.

In Cities and Regions

- Development of a regional circulating and ecological sphere: Cities and regions utilise resources according to their respective characteristics to form an independent and decentralised society, while complementing and supporting neighbouring regions and regional resources. Through such efforts, the "regional circulating and ecological sphere" is developed and expanded.
- Creative ideas and recognition: The concept of a city expanding via urban sprawl as its population increases is transformed into the creation of smart cities and regions whose net-zero infrastructure is inclusively and efficiently linked through digital communication networks. Likewise, unprecedented rapid population decline can be seen as an opportunity for social change. In this way, ideas and perceptions are changed drastically and all areas of living space are recreated.
- Implementing evolving net-zero infrastructure: In every part of a decentralised city and region, implementation of net-zero infrastructure is progressing, new digital networks and individual pieces of equipment are installed, and new jobs such as those for maintenance of these installations are created. Solar panels are installed on roads and parking lots, and power storage and wireless power supply are also used. The number of cars running in the city is decreasing, and there is almost no use of internal combustion engines. The logistics of collecting, transporting and delivering goods are highly developed with minimum time and energy. For buildings, ZEH and ZEB become standard specifications. AI analyses huge amounts of data collected through IoT, and suggests appropriate options through accurate recognition of the surrounding environment and by making predictions, as well as suggesting options for response.
- Institutional promotion of net-zero infrastructure development: In order to accelerate the expansion

of net-zero infrastructure construction in prefectures and municipalities, various schemes are put in place using rational standard-setting, regulations, subsidies and tax preferential treatment. These schemes promote the transition to new businesses that build resilient and net-zero infrastructure [85].

- Building high resilience areas through collaboration: Resilience in cities and regions is enhanced through collaboration using communication networks linking the national government, prefectures, municipalities, and communities, enabling them to adjust to global risks such as climate change, leading to rising temperatures [86], pandemics, cyber terrorism and challenges to security. The construction of cities and regions progresses so that each and every person can enjoy a safe and secure life, thereby guaranteeing quality of life, including peace, health and welfare for all.
- Eco-literacy improvement at the regional decision-making level: With synchronised infrastructure, anyone is able to access the information and experience necessary to realise a net-zero world. As a result, the eco-literacy of local communities and regional societies is enhanced. Cities and related infrastructure are re-organised with the aim of improving energy efficiency and to assist fuel conversion.
- Convenient and comfortable living space: By consolidating urban functions, all services necessary for living can be covered within walking distance. For commuting and accessing entertainment, people generally use public transportation that makes extremely efficient use of energy: people use buses and trains that are automatically driven by AI and flexibly stop at optimal locations. Passenger vehicles or buses are split into several carriages according to the number of passengers. People can freely choose the most suitable transportation (including walking and biking) and the best transportation route according to whether the purpose is to reach the destination quickly or to gain some health benefits. Thus, life satisfaction increases.
- New business development: There is progress in the installation of PV modules on agricultural land (so-called solar sharing) and introduction of vegetable factories. The combined services of businesses such as renewable energy generation, high-quality vegetable sales, and restaurants, are common business practices, and local production for local consumption is enhanced in suburbs and rural areas (farmland and mountainous areas), which result in support for employment and revitalisation of the regional economy.
- Enhancement of disaster prevention and mitigation: From the viewpoint of disaster prevention, and mitigation and adaptation of climate change, there is progress in reconstruction of housing and industrial infrastructure, taking into account the vulnerability of cities and regions. Resilience is improving everywhere in mountain areas, river basins, and coastal areas, creating safe and secure living spaces.
- Utilisation of unused land: Areas of unused land are utilised to expand negative emission technologies such as afforestation, Bio-Energy with Carbon Capture and Storage (BECCS) [87], and CO_2 direct air capture and storage (DACS). DACS is installed close to suitable storage sites where

safety can be confirmed (coastal areas and inland non-resident areas), and the heat source is supplemented by solar heat and gas combustion (with CCS). Furthermore, solar panels are installed according to the characteristics of the land, with wind power generation being well established in suitable areas. In addition, the land is used as a production site for fuels of biomass power generation and "bio-charcoal", a soil improvement material made from biological resources.

Box 6 Blockchain Technology that Promotes the Introduction of Renewable Energy

Renewable energy comes from distributed power sources. While there are many small-scale generation companies on the supply side (sellers), there are also small-scale consumers (buyers) such as small businesses and homes on the demand side. Generally, the transaction cost is a significant barrier when a small-scale seller and a buyer carry out a financial transaction. This is because it is necessary to go through an intermediary to give credit to the transaction, even if it is for a small amount. The transaction costs in current financial services are a heavy burden.

However, transactions using Blockchain change the conventional form of transaction. First, transactions using Blockchain are less likely to be fraudulent because the entire transaction history is recorded. Confirmation of each transaction by a third party becomes unnecessary, so the transaction cost is greatly reduced. Second, all procedures related to Blockchain are available online, and the contract information is also written into the Blockchain. Business is likely to become much more efficient so the cost of storing contract contents becomes unnecessary. Third, since all transactions are recorded, the electricity retailers can track the amount of power generation by power source, and add an environmental value to the commodity of renewable energy. Consumers may also select electric power as product based on highly reliable information. Furthermore, since all transactions are recorded, it is possible to develop a power supply service using storage batteries and electric vehicles. In Japan, Minna-denryoku Inc. provides electric power retailing services using Blockchain technology [88].

In Daily Life

(How to make the best use of time)

- Due to advancements in AI and ICT, working hours decrease, and there is more free time available for private purposes. While nature-derived renewable energy sources such as wind and solar power generation become the major energy sources, time can be used more flexibly across the whole of society, and human life can be customised depending on climate and weather conditions. In general, when people allocate their time effectively, their productivity rises.
- Due to progress made in remote working and an increasing number of holidays, people can spend half of the week in suburban resort areas, combining work and vacation ("workation").
- Time spent waiting for and travelling on public transport is more effectively used for other purposes. Technological advances related to VR, virtual space and holograms make it easier to access high-resolution three-dimensional information. Advances in sensor technology also make it possible to carry out work more efficiently.

(Value and practice)

- An advanced sound material-cycle society or circular economy is realised. Reuse and recycling are established, and the cost of "discarding" is properly recognised at the individual level. Furthermore, in combination with institutional measures such as incorporating externalities (transaction costs) into prices and fees. Individuals and societies can break away from the mass-disposal system.
- People's value shifts from "ownership value" to "functional value", the sharing economy is firmly established, and the materials and energy required to achieve the same utility greatly decrease across the whole of society.

(Travel and movement)

- For long-distance travel, the use of public transport such as self-driving buses and taxis is encouraged. Autonomous driving significantly reduces delivery costs and delivery time [89], and makes it easy to send luggage to accommodation facilities and major transport hubs.
- It is much more convenient for people living in the city centre to use public transportation. This is a dramatic change from previous lifestyles, when people used their own cars to shop at supermarkets.
- There is development of high-performance wheelchairs, self-propelled equipment, moving sidewalks and panels, and other products to ensure elderly people can move around safely. Mobility is diversified, including transportation in the air using technology such as a multi-copter.

Box 7 Energy Efficiency Improvement with Electric Vehicles

It is said that the energy efficiency of gasoline in current gasoline vehicles is 30-40% [90]. In contrast, the energy efficiency of electricity in electric motors is 80-90% [91]. Therefore, an electric car requires less than half the energy per kilometre for both primary and secondary energy. In addition, even when an electric vehicle runs using the power generated by the latest gas-fired power generation (power generation efficiency is 52% at the power transmission end), the required amount of primary energy is equal or less, compared to a vehicle run on gasoline.

(AI, ICT and other technological advances)

- There is a change in the way people purchase everyday products such as food and daily necessities. Each consumer simply chooses goods suggested by AI technologies that have learned her/his purchasing patterns.
- Wearable devices, ultra-small chips and high-precision sensors make identification of individuals faster and more accurate. New devices such as VR transform and improve efficiency in various aspects of everyday life such as authentication, purchasing, and confirmation of health status.
- Blockchain technology, which enables reliable, low-cost transactions of small amounts of anything including money, means that many products can be reused and shared, thereby increasing resource efficiency [46]. Services that connect people to businesses rooted in the region are developed. For example, new ideas for services that use local currencies are becoming easier to realise using Blockchain technology [92].
- Many general-purpose products can be manufactured on-site using various types of 3D printers [93], and long-distance transportation of products is significantly reduced[17].

(Housing)

- There are no CO_2 emissions from any homes or offices due to progress made in rehabilitation and renovation, as well as technologies that promote improved energy use efficiency such as high insulation, rooftop/wall sunlight, and heat pumps including high-performance air conditioners, and compatible all-electric appliances (e.g. IH cooking heaters)[18]. Thin and light organic thin-film solar cells [94] are used for solar panels on walls, and transparent organic thin-film solar cells are used for windows.

[17] Due to the sharing of goods, the production volume of new products is also decreasing.

[18] Of the energy consumed by one household in 2017, the energy used for air conditioning and hot water supply was 28.1% and 29%, respectively [141]. For air conditioning, products with an APF (Annual Energy Consumption Efficiency) of more than 7 are commercially available. For hot water supply, products with APF of more than 3 are commercially available [142].

- Many regions switch to electrification for energy use[19]. Old houses become better insulated through rebuilding and renovation, so that even in winter, it is sufficient to use an air conditioner and geothermal heat and there is no need to use kerosene or gas heaters for heating. In some areas such as Hokkaido and Tohoku / Hokuriku regions where there is a large demand for heating in winter, waste heat from waste incineration facilities is supplied to neighbouring buildings and roads through heat conduits.
- Whilst previously, multi-storey housing and commercial buildings used reinforced concrete and steel frames as the main materials for construction, some high-rise building use building materials made up to 90% of wooden materials such as cross-laminated timber (CLT) (Box 8).

Box 8 Wooden Construction of High-Rise Buildings

Obayashi Corporation started construction of Japan's first high-rise fireproof building made purely of wood (1 basement floor, 11 floors above ground) in July 2019. Furthermore, it achieved Net-Zero Energy Building Ready (ZEB Ready) by improving the performance of the exterior of the building and using natural energy [95]. This building is funded by the issuance of green bonds. There is a possibility that building materials will change significantly as investment systems of financial institutions change in the future. Sumitomo Forestry announced a plan to build a 70-storey wooden high-rise building at a height of 350m in central Tokyo by 2041. As to whether such a building would be able to withstand major earthquakes, it is said that safety was confirmed up to a magnitude 8 class quake. In the future, the company plans to overcome issues such as the availability of materials and fire resistance.

[19] Using hydrogen in the household sector is also a means of decarbonisation, but this report does not assume this option due to the following reasons: 1) It is necessary to establish technology that can transport 100% hydrogen gas in city gas pipelines (for example, pipelines are all polyethylene pipes). Even if the pipelines are replaced, existing technology can only contain hydrogen at a volume ratio of 20% [143]); and 2) sufficient heat demand is needed to increase fuel cell energy efficiency. But heat demand in warm areas and small households is not sufficiently high.

(Health)

- People wish to extend their healthy life expectancy, and health consciousness is increasing. Prevention of disease is improved through a wearable device that assesses the wearer's physical condition, and combines this with analysis using deep-learning information. Feedback is then provided to each individual. In particular, the prevention of lifestyle-related diseases becomes common, avoiding excess eating. In food markets, the majority of products are healthy goods.

(Safety and disaster prevention)

- The intensity of typhoons and heavy rains is greater. As a result, landslides, road closures, power outages, water interruptions, and other disruptions to infrastructure become more frequent. For this reason, there is more individual awareness about disasters. With the aim of ensuring safety, people are able to independently secure energy at home, and work in a flexible manner, which minimises the impact of a disaster when it occurs.

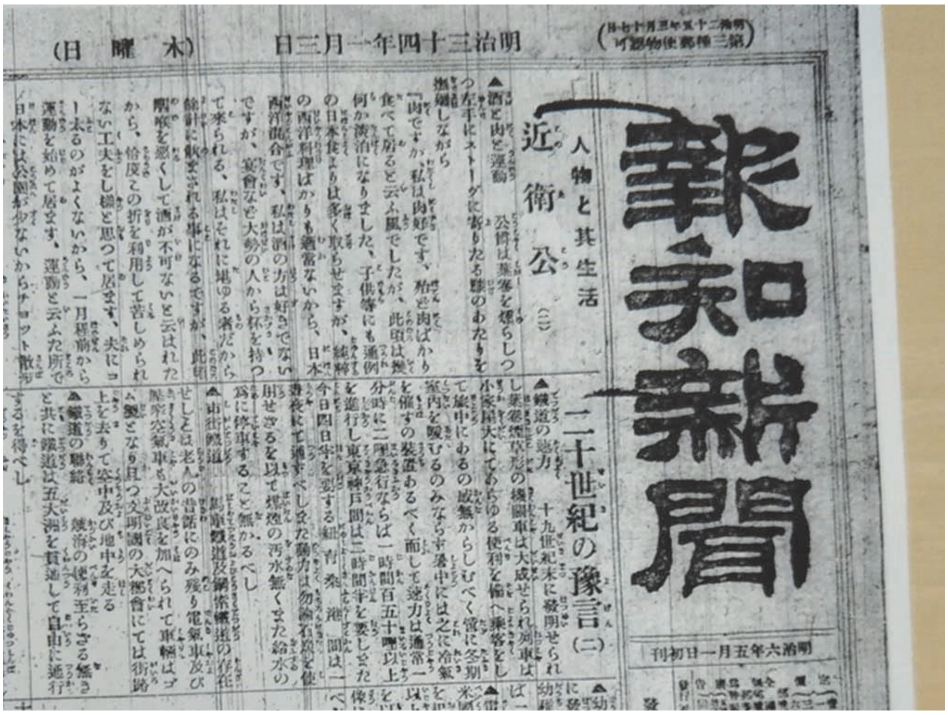
Illustration by ad-manga.com

Box 9 Predicting the Future

Recently, many people have pointed out that the rate of social change is remarkable, and in fact accelerating. Historically, the influence of the agricultural revolution took one thousand years to spread through societies, while the industrial revolution took hundreds of years, but the information revolution transformed society in decades [96]. Changes in society are not predictable by nature, but it may make a difference in subsequent social development if people have dreams and hopes for the future.

In 1901, more than 100 years ago, the Japanese newpaper, Hochi Shimbun, made a forecast about what science and technology would be realised within the 20th century, known as "A Prophecy for the 20th Century" (January, 1901). The following points are a partial translation of that article:

- ✓ Correspondents will be able to remain in Tokyo and write the latest articles on war with photographs in natural colours without going to the battlefields in Europe.
- ✓ It will be possible to whisper sweet nothings to a lover from a distance of 10 miles.
- ✓ Shopping will be possible instantly from a product catalogue, with the product delivered via an underground pipe.
- ✓ A round-the-world trip will take seven days. (In 1901, it took 80 days)
- ✓ It will be possible to predict natural disasters one month in advance. Typhoons will be turned into rain using a cannon-like device (to lessen their impact).
- ✓ Electricity will become fuel as wood and coal run out.
- ✓ Vegetables will be grown using electricity.
- ✓ Mosquitoes and fleas will become extinct.
- ✓ Humans will be able to interact freely with dogs, cats and monkeys, and dogs will run errands.



報知新聞

明治三十四年一月三日 (木曜日)

人物と其生活 近衛公

二十世紀の豫言(二)

Figure 14 Hochi Shimbun "A Prophecy for the 20th Century" (3 January, 1901) (Source: National Diet Library, Japan)

In Industrial Activities

- Resource productivity is improved by topological optimisation[20], and overall productivity increases. Due to highly accurate marketing and flexible dynamic pricing, unsold stock is reduced, as well as being reused and recycled. Product samples are made increasingly in 3D / VR form, there are fewer misunderstandings due to advertising, and less trouble immediately after purchase. Furthermore, individual requests from consumers for goods and services are easily customised.
- Management priority shifts from the shareholder-first principle to stakeholder capitalism [97], which prioritises contributions to all stakeholders such as customers, business partners and local communities. Due to requests from financial institutions and business partners, actions on decarbonisation and SDGs become a minimum requirement for company business.
- The development of social networks means that companies must take more responsibility and be accountable for their activities, and ensure that this becomes common practice.
- ESG becomes essential as a screening standard for the investment of financial institutions. ESG also has increasing significance as a driver of economic and social transformation for climate change countermeasures.
- In energy-intensive industries such as steel, chemicals and cement, decarbonisation-type manufacturing technologies such as electrification, hydrogen, CCU / CCS technology, and biomass utilisation are standardised and their proper production is introduced (Table 7).
- In the iron and steel industry, pig iron is produced from iron ore through hydrogen reduction and electrolysis [14,15,98–100]. Regarding industrial processes that cannot be decarbonised with these technologies, CCS is utilised to capture CO_2 from them. Furthermore, with the development of a circular economy (reduction in new demand for domestic steel and progress in the recycling of steel scrap) and the spread of arc-type electric furnaces that run on 100% renewable energy, a recycling system is established to produce steel from scrap that meets necessary quality requirements [15,20].
- In the chemical industry, olefins are produced based on synthetic gas that uses hydrogen derived from renewable energy and CO (carbon monoxide) converted from CO_2 recovered from biomass or the atmosphere. Olefin refining by reforming natural gas will be performed as a transitional technology until synthetic gas becomes commercially available. So-called green chemicals are produced from non-edible biofuels such as algae [101,102]. The demand for plastic products decreases due to the formation of a circular society, while the demand for expected new materials, such as carbon fibre and cellulose nanofiber carriers, may increase.
- In the cement industry, fuel- and process-related CO_2 is generated during the process of calcination of limestone to produce clinker. CO_2 emissions from fuel are reduced by measures such as

[20] Technology that optimises the shape by removing unnecessary materials.[112].

electrification, hydrogen utilisation, and biomass utilisation. CO_2 emissions from the manufacturing processes are captured by CCS technology. Alternatively, the use of raw materials other than clinker reduces the amount required. In a circular economy, the cement industry plays an important role helping to incinerate industrial waste.

- In the pulp industry, mainly in the energy-intensive digestion process, decarbonisation is achieved by electrification (using heat pumps [103]), hydrogen utilisation and biomass utilisation. There may be less production demand for the paper pulp industry due to factors such as the digitalisation of newspapers, books, and documents, but there may be more demand in response to the plastic waste issue, such as the use of paper products as a plastic substitute (such as food containers) and dissolving pulp (such as containers and packaging, textile fibres) [104,105].
- In other manufacturing industries, electrification progresses because high-temperature heat demand is limited (Figure 15). The following electrical technologies are used to produce heat such as resistance heating, induction heating, dielectric heating, infrared heating, arc/plasma heating, laser heating.
- Fluorine-based GHGs (HFC, PFC, NF_3, SF_6) emitted by the industrial sector have much higher global warming potential (GWP: a value representing the intensity of global warming impact based on CO_2 as 1) than that of CO_2. Progress is made to convert HFCs, used mainly as a refrigerant for refrigerators and air conditioners, into alternative hydrofluorocarbons (CO_2, NH_3, HFO refrigerants [110] with GWP in the single digits are developed and spread). In addition, zero emissions are mostly achieved by implementing downstream measures such as refrigerant collection, recycling and disposal.
- HFCs used as extinguishing agents, foaming agents, liquid-crystal display panel manufacturing, HFC by-products during HCFC manufacturing, semiconductor manufacturing, and solvents are also converted to low-GWP substances such as HFO, CO_2, and NH_3. Regarding PFC, NF_3, SF_6, net-zero emissions are mostly achieved by using abatement devices (abatement efficiency of 90% or more) in the processes of aluminium production, electrical equipment, liquid crystal production, magnesium casting, PV panel production, and semiconductor production. Energy efficiency and safety are also increased by making efforts to lower GWP using alternative hydrofluorocarbons [111].

Table 6 Uses of Dissolved Pulp

Processing Method	Product,	Main Usage
Dissolution	Regenerated cellulose	Rayon, cellophane
Hydrolysis	Microcrystalline cellulose	Excipient (medical), Food additives
Derivatisation	Carboxymethyl cellulose	Food additives, Civil engineering materials
	Cellulose acetate	Artificial fibre, Cigarette filter, Liquid crystal film

(Source: Oji Paper Holdings Corporation[105])

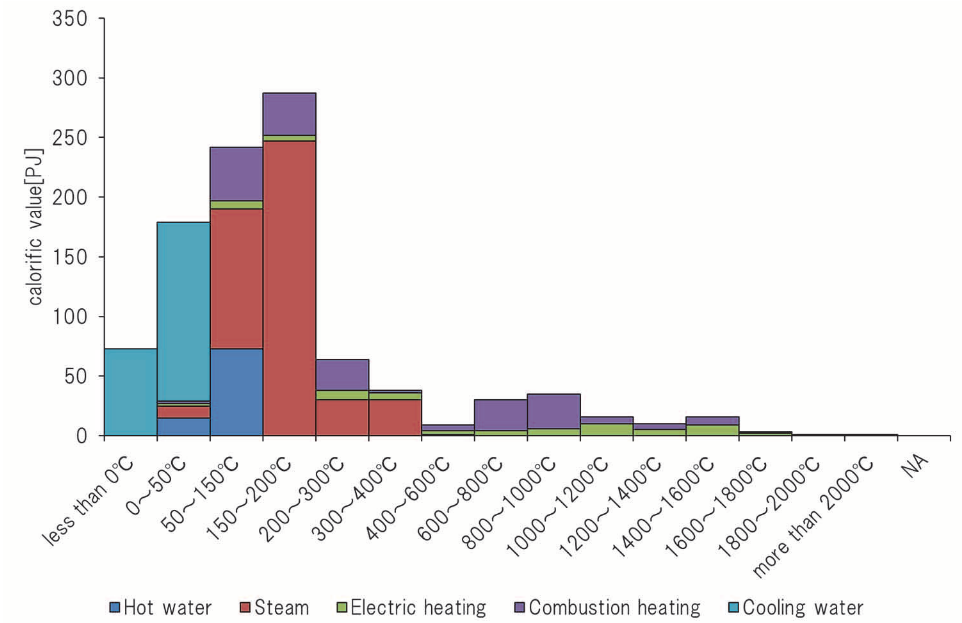


Figure 15 Heat demand by industry and temperature zone in the manufacturing sector excluding heavy and chemical industries

(Source: Produced by IGES based on the Mitsubishi Research Institute, [106])

Box 10 Japanese companies that are evaluated for their actions on SDGs

Sekisui Chemical Co., Ltd. was ranked 12th in the world in the Global 100 Index by the Canadian publisher, Corporate Knights (2020 version).

This ranking, including 7,395 companies with annual sales of more than USD 1 billion, was based on 21 original SDG-indicators, including environmental and social impacts of products, carbon dioxide and waste, and promotion of female employees to executive positions. Sekisui Chemical Co., Ltd. was ranked top in Asia, as about 28% of its revenue was estimated to contribute to achieving the SDGs.

Table 7 Overview of Low-Carbon Technologies Applicable to Energy-Intensive Industries

	Electrification (heat and power supply)	Electrification (utilisation in processes such as electrolysis/electrochemistry (excluding hydrogen))	Hydrogen (use in heat supply or process)	CCU	Biomass (providing heat and raw materials) and biofuels	CCS	Others (including integration of processes)
Steel	**xxx**	xx	xxx	xxx	x	xxx	Abolition of intermediate processes and recycling of process gas: xxx High-quality steel recycle: xxx
Chemistry /Fertilizer	xxx	xxx	xxx	xxx	xxx	xxx(*)	Utilisation of several types of waste (chemical recycling): xxx
Cement / lime	xx	o	x	xxx	**xxx**	xxx	Substitute for binder materials such as clinker: xxx Streamlining the use of cement in concrete: xxx Use of waste fuel: **xxx**
Paper/ pulp	xx	o	o	o	**xxx**	o	Efficiency improvement: **xxx**
Ceramic	xxx	o	xx	x	x	o	Efficiency improvement: **xxx**
Glass	xxx	o	x	o	xxx	o	Advanced glass recycling: xx
Non-ferrous metal/ alloy	**xxx**	**xxx**	x	x	xxx	x	Efficiency improvement: **xxx** Recycling high-quality non-ferrous metal: xxx Inactive electrode: xxx
Petroleum refining	xx	o	xxx	xxx	xxx	xxx	Efficiency improvement: **xxx**

o: Meaningful adoption is limited or not expected
x: Utilisation is possible, but major and widespread utilisation is not expected
xx: Applicable to some degree
xxx: The technology is already applied on a large scale (in some cases, it may be possible to further expand its utilisation)
xxx: Already commercially available
(*) Especially applies to the production of ammonia and ethylene oxide
(Source: Produced by the authors based on High-Level Group on Energy-Intensive Industries[107])

In Agriculture, Forestry and Fisheries

- Renewable energy is fully utilised in agricultural and fishing areas, and zero CO_2 emissions are achieved in the production and distribution process due to electrification of agricultural and forestry machinery and fishing boats, as well as through the use of fuel cells and ammonia related technology [108].
- With the development of sensor technology and AI technology that processes data obtained by sensors, it becomes possible to confirm growth status, maximise the efficiency of work hours and fertilisation, and improve crop quality. The performance of cultivating and harvesting robots is also improved. These changes significantly improve the labour productivity of all livestock farmers and foresters [109].
- There is increased demand for domestically produced high-value-added agricultural and forest products, and there are more activities in agriculture and forestry through improvements in the traceability of food, daily necessities, and construction materials.
- There is an increasing urban population due to concentration of urban functions and improved labour productivity due to telework. Urban agriculture and forestry and urban farming by citizens are promoted due to an increase in people's awareness about food and nature. Thus, the role of agriculture and forestry provides new added value. In particular, progress is made with local farming and ecological activities in areas considered as "Satoyama" (places where nature and people exist in harmony) and initiatives to create gardens at home and on rooftops. There is also more conservation of soil to support the ecosystem, agriculture, and culture with the concept of permaculture [110].
- Wood is increasingly used as a material for buildings. As of 2017, 44% of Japan's artificial forests were cedar [111]. Due to technological advances such as the Kebony process [112] and AFRW (Advanced Fiber Reinforced Woods), cedar wood is becoming higher-grade and higher-strength. Thus, new market demand for cedar is increasing. The amount of CO_2 absorbed by forest activity is increased due to greater use of domestic timber and the rejuvenation of planted forests. Revitalisation of forestry helps to promote the economy of rural areas [113,114].
- Solar panels are installed on some farmlands. Wind power is established in suitable areas. Furthermore, biomass power generation is also implemented in forest areas. The income from power generation activities grows and supports agriculture and forestry.
- In addition to afforestation and reforestation, the use of "bio-charcoal", a soil improvement material made from biological resources, serves to absorb CO_2 and increase crop yields [115,116]. In some areas where safety is confirmed, BECCS that combines biomass power generation and CCS, is installed. These negative emission technologies contribute to net-zero.

In Adaptation

- As we face the reality of the climate change crisis, people are more likely to share perspectives and values such as “no one is left behind” and "each person is valued". The bonds between regions, communities and families deepen, and the basic concept shifts from “public disaster prevention” to “adaptation based on mutual assistance and self-help”. These changes come about due to the "sixth industrialisation" of agriculture and forestry that contributes to the conservation of Satochi Satoyama. There is also more awareness about how the integration of hobbies and volunteer activities at the grassroots level contributes to the community because of their increased longevity due to progress made by medical technology and increasing health consciousness.
- Synergies between adaptation and mitigation are enhanced, creating a society in which these two processes are integrated. For example, forest development, as part of adaptation measures and disaster prevention, contributes not only to ecosystem conservation but also to the mitigation of climate change. Adaptation measures involving land-use conversion, such as the transfer of housing and industries away from the middle and lower reaches of rivers, will trigger reinvestment in the city's infrastructure, and will promote mitigation toward net-zero through zero emissions from buildings such as ZEB and ZEH. There will also be progress made in distributed power generation that enables flexible demand response, and practical use of VPP (Figure 16).
- Considering the uncertainty of temperature rise, "transformative adaptation” takes place that involves changes in urban development and land use plans and relocation of residences and industries, in addition to a policy mix including both soft and hard measures. It is common that residents refer to hazard maps when they make real estate transactions. As a result, the forms of cities and areas incorporate climate change risks.
- New adaptation mechanisms to flexibly deal with uncertain situations are systematised and become widespread. An approach that aims to introduce accurate and prompt adaptation measures using local climate forecasts has already been implemented [117]. In addition, “Adaptive management” [118,119], which enables stepwise decision-making by using forecasts and observations together to prepare multiple alternatives, is implemented in municipalities and communities.
- In order to deal with increasingly severe climate change impacts that exceed our experience and knowledge, people who can come up with new and innovative ideas relating to adaption based on scientific evidence play an important role in regional revitalisation. They do so by, for example, proposing new business models that take advantage of climate change, including expanding cultivation areas due to rising temperatures.
- Digitalisation creates opportunities to improve the adaptation behaviour of all actors. Advances in AI-based prediction technology and ICT provide real-time accurate and high-resolution information across time and locations, enabling better adaptation countermeasures, including

changes in people's behaviour. For example, by comparing the AI-based river flow rate forecasts and evacuation advisories of the government with images from surveillance cameras, residents can make more accurate judgments about whether they should evacuate or stay at home.

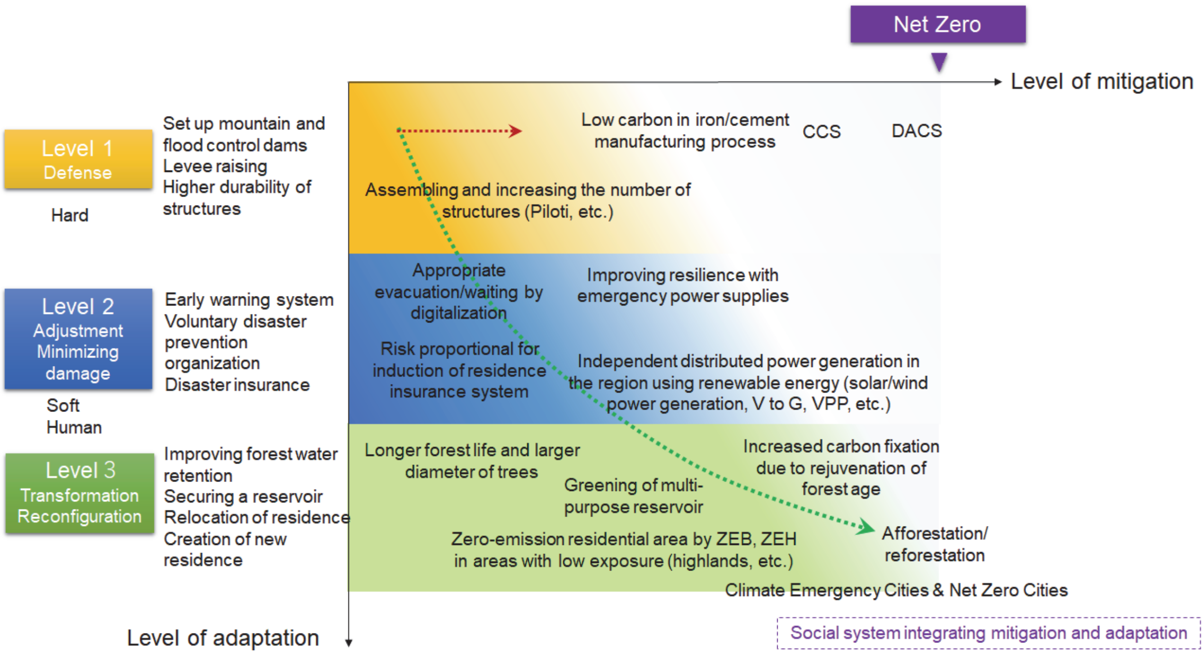


Figure 16 Integration level of adaptation and mitigation toward net-zero (example of water disaster field)

Source: Authors based on Shirai et al. [118]

Box 11 Digitalisation and adaptation

Adaptation is principally based on an understanding of information about climate change impacts. Therefore, with the development of ICT, digitalisation provides accurate and high-resolution information across time and locations and creates an opportunity to improve adaptation behaviour by all stakeholders in all affected areas. Ultimately, if more reliable information is available, everyone will be able to take more appropriate and effective adaptation actions and live more safely and securely. For example, real-time prediction and alerts about short-term heavy rainfall will be significantly improved because AI analyses big data related to cloud generation processes and radar observation of rainfall through IoT technologies. As a result, it can dramatically increase the effectiveness of actions for disaster prevention and adaptation. In addition, dramatic progress has been made in computer performance, so the spatial accuracy of climate models for long-term prediction of climate change and the prediction accuracy could be much improved. Although measures differ depending on the affected areas such as agriculture and health (e.g. heatstroke), digitalisation is generally considered to be an effective way to improve the accuracy of the adaptation measures taken.

While information on the impacts of climate change is important, it is also vital to have information on how hard infrastructures are affected, people's locations, and the geographical environment to reduce the overall risk of climate change. For example, advances in observation technology such as sensors installed in infrastructure and earth observation satellites make it possible to accurately understand the people, land assets, and ecosystems that need to be protected, and facilitate adaptation actions. For hard infrastructure, low-cost non-manual maintenance can be conducted by robots, using remote monitoring technology such as drones and through radar inspection using electromagnetic waves [120]. Looking at adaptation from the perspective of software and humans, people can enjoy the benefits of disaster prevention expected in Society 5.0 through safe evacuation based on accurate information by AI, quick rescue by power-assisted suits and rescue robots, and optimal delivery of supplies by drones and flying vehicles [27].

Since a society with renewable energy as a major energy source will have been built by 2050, people will strongly recognise the importance of securing energy systems that are resilient in the face of extreme events such as storms and short periods of heavy rain. With the progress of digitalisation, it will be possible to take appropriate measures in advance based on information about the route and arrival time of the storm as well as its intensity (precipitation and wind conditions). In the case of a disaster and the time period afterwards, an autonomous decentralised emergency power supply network linked to electric vehicles will enable continuous power supply in the area.

Illustration by ad-manga.com

Chapter 3: Toward the Realisation of a Net-Zero World

Issues and Challenges for a Just Transition

The transformation to a net-zero society requires a combination of changes by all actors in every corner of society, ranging from corporate activities to individual behaviours, as well as changes in politics and the economy. This is what is really meant by a "decarbonising revolution". For this reason, possible objections that are based on potentially negative aspects caused by any changes must also be considered and addressed in order to ensure broad societal support for the transition. The transition should be based on the concepts of ″leaving no one left behind″ and ″just transition″. In this section, we will present our thoughts on potential negative aspects and objections to the social change which is needed to realise a net-zero world.

- Issue / challenge 1

It is not reasonable for Japan alone to establish a net-zero society if the rest of the world does not also do so.

Our line of thinking: At present, some countries actually do see the response to climate change as an opportunity to enhance economic prosperity and have set a net-zero world as a long-term goal. Especially in Europe, concrete actions are being taken based on comprehensive and robust national and regional strategies such as the European Green Deal. In developing countries as well, for example in India, the government is considering specific measures to achieve significant CO_2 reductions in the steel sector [121]. Japan's long-term climate strategy ("Long-term Strategy under the Paris Agreement") is positioned as a growth strategy. Furthermore, it states that "We will lead international discussions, including the creation of frameworks and standards in the field of climate change"[28]. According to the latest Carbon Disclosure Project (CDP) report, a large number of Japanese companies are ranked at the highest level (A rank), and in fact, Japan has the most A-ranked companies compared to other countries. It is not an exaggeration to say that some efforts have been made by Japanese companies to ensure that they are positioned as international leaders.

Unfortunately, Japan has often been given the Fossil of the Day award by an international NGO at the Conference of the Parties to the United Nations Framework Convention on Climate Change (COP), and is recognised as a country with a "coal addiction". Another issue is that the international community expects Japan to strengthen its efforts, such as dealing with the problem of coal-fired power generation and increasing the degree of ambition in its net-zero national goal. Therefore, it is critical to set a target year for the net-zero national goal as soon as possible, and then work steadily to implement it. To do this, it is important to carry out the following:

1) Exert leadership within the international community, and actively promote the cooperation of other countries,
2) Have the national government proactively send out signals to mobilise private finance for businesses and industries, in response to climate change risks.

Moreover, it is important to promote a well-balanced discussion, with the younger generation, about the benefits and returns obtained by achieving a net-zero world.

Box 12 Japanese Companies Evaluated for Climate Change Measures

The British international environmental NGO, Carbon Disclosure Project (CDP), conducted a questionnaire survey of companies around the world regarding their climate change countermeasures and evaluated them using nine levels. According to the 2019 report, 38 Japanese companies were rated A (highest level) and 42 Japanese companies were rated A- (second highest level), which put Japan in the top rank by country. In general, we can say that the companies were highly evaluated for their efforts.

- Issue / challenge 2

Concerns about the international competitiveness of manufacturing industries when trying to achieve a net-zero world.

Our line of thinking: This concern is based on the idea that the more stringent an emission reduction is, the more costly the countermeasures, and the higher the electricity price will be. Therefore, there is a fear that domestic manufacturing industries will lose international competitiveness due to higher costs in a net-zero world.

This fear is from the viewpoint of protecting manufacturing industries, which play a key role in the Japanese economy, and this issue needs to be faced head-on when searching for the path to a net-zero world. Looking back at some past cases, strict environmental (atmospheric) regulations actually strengthened the international competitiveness of the Japanese automobile manufacturing industry by triggering rapid technological innovation [122]. It is important to consider the international movement to decarbonise as an opportunity for technological transformation and innovation, including society/lifestyle, and growth.

The European Green Deal (Box 1) states that the steel, chemical and cement industries are essential to the European economy, and that decarbonisation and modernisation will be promoted in these areas. Japan should take similar measures supporting these industries so they can actively introduce the technologies shown in Table 7, "Overview of low-carbon technologies applicable to energy-intensive industries".

In the future, when the transformation to a net-zero world progresses, no doubt every corner of the world will develop net-zero infrastructure in key areas such as renewable energy, movement/transport (including logistics), construction, and the digital communication network that integrates them. Supported by the spread of such net-zero infrastructure such as storage batteries, wireless power supply, and technologies related to ZEH and ZEB, it will be possible to see significantly increased performance not only in EVs but also in the manufacturing and service industries. Some important issues will be technology and cost of mitigation measures in energy-intensive sectors such as the steel and cement manufacturing industries. However, it is unlikely that the global trend toward decarbonisation will be reversed, so it is necessary to implement technological innovations and management reforms promptly, and to create a system for raising corporate profits in the context of long-term decarbonisation after 2050. Postponing the transformation of companies to net-zero operations may in fact cause more damage to their international competitiveness than adapting earlier.

- Issue / challenge 3

The potential supply of renewable energy in Japan may not be enough to achieve net zero.

Our line of thinking: Japan's final energy consumption in 2015 was about 13.5 EJ (= 3,750 TWh). On the other hand, the theoretical renewable energy potential (the amount of energy excluding natural factors such as elevation and slope, legal regulations such as natural parks and protected forests) is calculated at 4,800 TWh[67]. This is made up of residential solar power, non-residential solar power, onshore wind power, offshore wind power, geothermal power, biomass, and small and medium hydropower plants. Therefore, with regard to the energy balance at the macro level, the entire final energy consumption, at the same level as that in 2015, can be met with renewable energy.

However, in reality, it is not possible to introduce all of the potential renewable energy, due to various physical constraints such as cost and site conditions. Even if it was physically possible, various other factors must be taken into consideration such as constraints in transmission and distribution networks, and the intermittency of renewable energy. This means the amount that can realistically be used is limited. JST's analysis [123] estimates that renewable energy could supply 100% of electricity, up to the level of about 2,200 TWh. This could be achieved by combining technologies such as new pumped storage hydroelectric power stations, and enhanced geothermal power generation on hot dry rock, even when taking into account the power generation costs of renewable energy and the system stabilisation constraints of the transmission and distribution network. Therefore, it would be possible to cover all the energy needed in Japan using renewable energy by boldly implementing measures to promote electrification and at the same time, curbing energy demand through the introduction of energy-saving technologies and energy-saving practices.

Furthermore, if the electric power generation potential of new technologies becomes feasible, for example ultra-high efficient solar power generation with efficiency of 40% or more on surfaces like sidewalks and parking lots, renewable energy could supply 100% of energy demand up to a higher level.

If solar and wind power generation would account for 50% of the total power source mix, the cost of increasing the necessary transmission lines is estimated to be about JPY 140 billion per year [124]. While further investment would be required for 100% renewable energy, these are sufficiently feasible figures to be considered on a nationwide scale. In addition, the power generation cost for each type of renewable energy has dropped significantly (Figure 17), and this trend is expected to continue.

- Issue / challenge 4

The price of renewable energy.

Our line of thinking: International renewable energy generation prices (in particular for solar, concentrated solar power and wind) have fallen sharply in recent years and have already reached levels which are competitive with fossil-fuel derived power generation costs (Figure 17). However, the problem is that the cost of generating power using renewable energy in Japan is much higher than in other countries. Taking solar as an example, the cost of solar cells (modules) has fallen globally, but the unique situation in Japan means that costs are higher for inverters and for the labour needed to install them [125]. In this regard, if each module can be made thinner and more transparent so that it can safely and easily be installed on a wall or window, it may lead to a reduction in labour costs. In Japan, there is still room to lower the unit price of solar power generation through technological innovation and mass production.

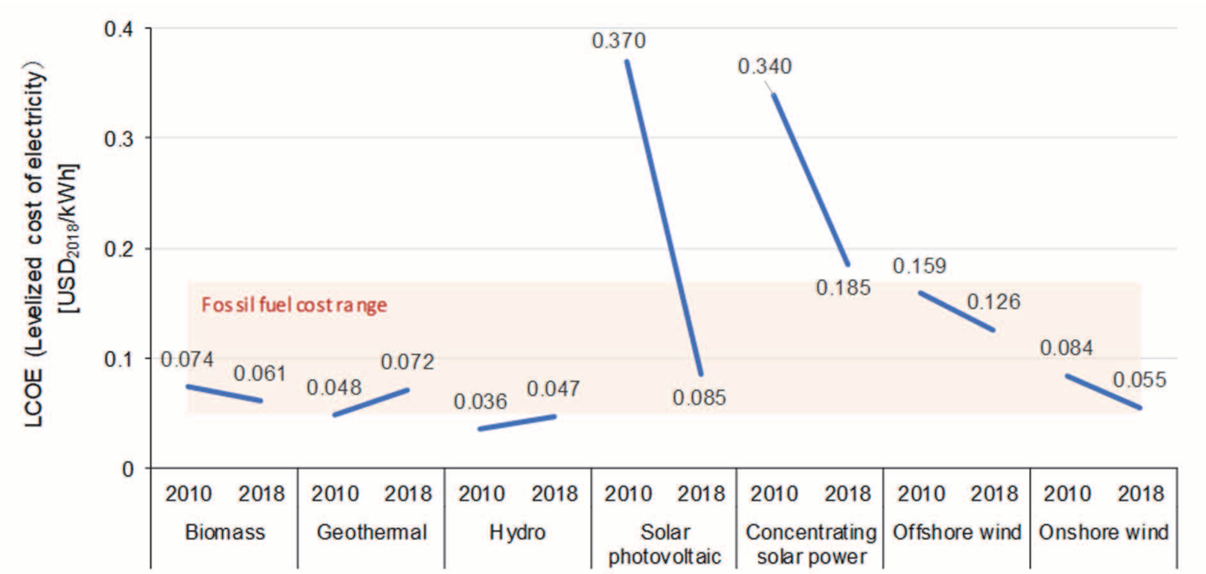


Figure 17 Changes in the Global Renewable Energy Power Generation Cost (Equalised power generation cost) (2010-2018)

Note: All values are weighted averages by world region

Source: IRENA [125] Figure S.1

➨ Issue / challenge 5

Technological constraints on increasing the use of renewable energy (e.g. grid connection).

Our line of thinking: One problem is that there is not enough free capacity in the grid to accommodate renewable energy. However, it is possible to expand the scope for supplying renewable energy to the grid even with the current system (doubling the scope) by managing power flow in short intervals, as other countries have done with their operating systems [126,127]. Germany met 100% of its power demand with renewables during a short time period of less than one hour [128,129]. There is ample room for promoting renewable energy from an institutional and technological perspective, including advancements in energy storage technology. In recent years, the price of batteries for electric vehicles dropped significantly, with a further reduction in price predicted at USD 150/ kWh after 2025, which is standard for large-scale diffusion of batteries (Figure 18). This makes it possible to use a large amount of variable renewable energy in the grid system.

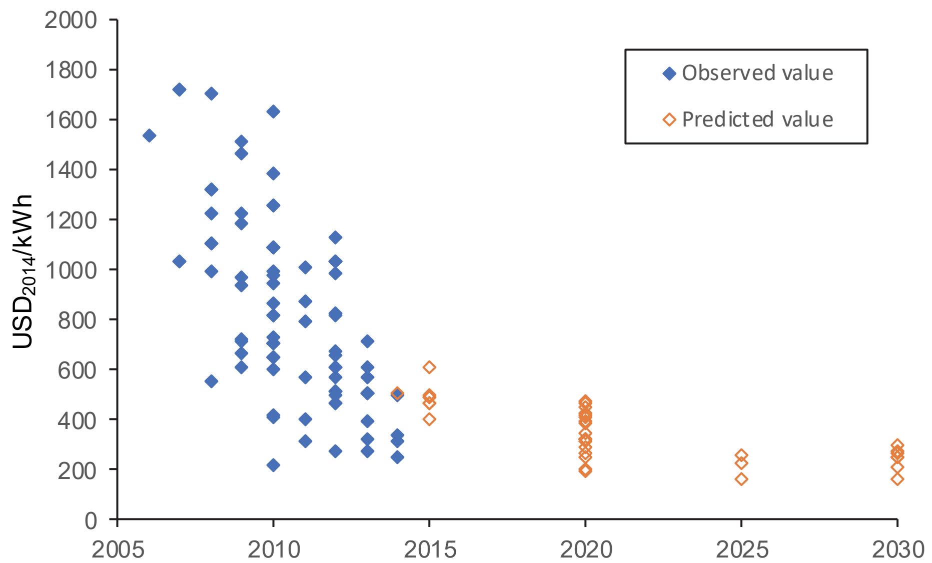


Figure 18 Cost of lithium-ion battery packs for electric vehicles: Measured values (up to 2014) and predicted values (up to 2030)

Source: Nykvist and Nilsson[130], Figure 1

- Issue / challenge 6

Employment issues and a just transition in fossil fuel-based industries (e.g. energy, materials, and petrochemical industries).

Our line of thinking: This is an extremely important issue globally. Fossil fuel-related industries were key for supporting Japan's post-war development, and they have played a particularly significant role since the start of the high economic growth period. On the other hand, some countries are turning to non-fossil fuels, as fossil fuels are the primary cause of climate change, and a significant shift in transitioning to a net-zero system is becoming a global trend. Under these circumstances, there is a demand for a just transition to minimise disruption to employment in fossil fuel-related industries. Within the next 30 years, up to 2050, it will be vital to promote just transition management with a view to securing alternative employment for the workers in these industries. For example, Germany decided to abolish coal-fired power by 2038 at the latest and will provide compensation of EUR 40 billion in the next 20 years for losses related to shutting down the mines and power plants [131]. Royal Dutch Shell is changing its management strategy and vision to shift from an oil company to an energy company focusing on natural gas and renewable energy. However, fossil-fuel related industries are unlikely to become totally obsolete in a net-zero society. Rather, knowing how to expand opportunities for GHG emission reduction is important. There are also possibilities to maintain the employment of workers through the introduction of hydrogen steel in the steel sector or conversion to bio-based materials in the chemical sector, as well as new business development related to net-zero infrastructure such as renewable energy. Positive discussions about a vision of the future that is compatible with a net-zero world will take us in a constructive direction.

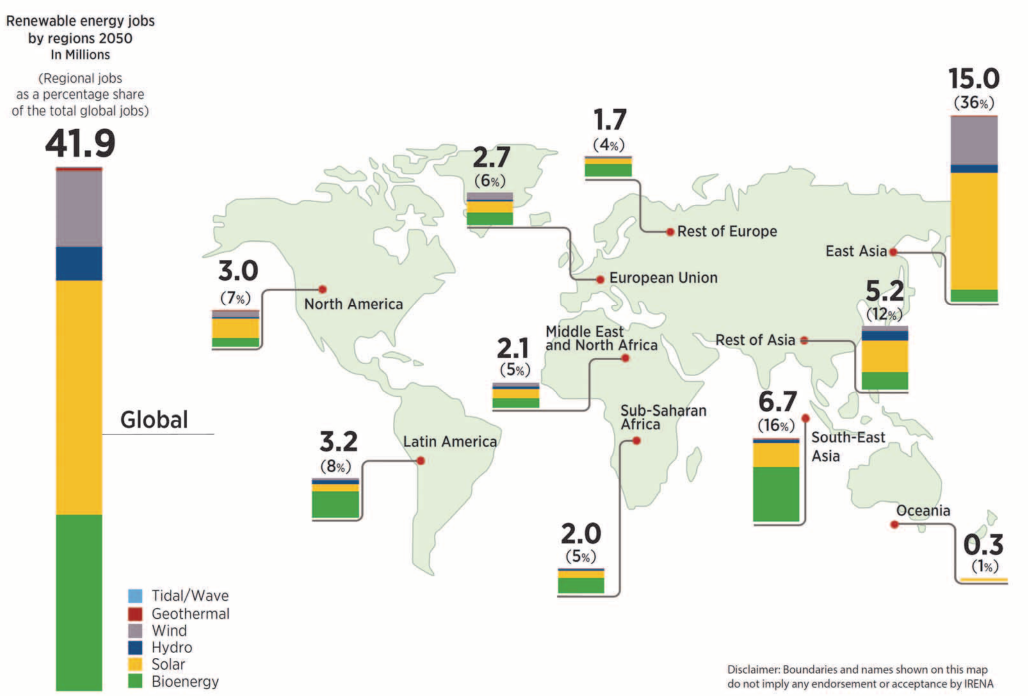


Figure 19 Renewable Energy Employment 2050 in the IRENA Energy Transition Scenario by Region
Source: IRENA[132][132][132][132][132][131][130] Figure 12

- Issue / challenge 7

Claims that net-zero goals are extreme and unrealistic.

Example No. 1: Achieving a net-zero world is very expensive. Even the reduction of GHGs by 80% or 90% will put a heavy burden on people. Some doubt whether it is necessary to reach the Paris Agreement targets of 2 ℃ or 1.5 ℃, and consider a net-zero world to be an extreme goal that is economically irrational.

Example No. 2: Since there is significant uncertainty, not only about climate change impacts but also about mitigation costs, it is essential to have comprehensive risk management through mitigation, adaptation, and climate engineering (geoengineering). The net-zero goal, which emphasises mitigation measures, is too extreme.

Our line of thinking:

Regarding No. 1: Most arguments promoting this view are based on the calculation results of integrated assessment models from the 1990s to around 2015, which indicated that the returns (benefit) on mitigating the impact of climate change are smaller than the cost of reducing GHG emissions [133,134]. However, recent studies have found that returns would be extremely large. New calculations include the effects of temperature rise on economic growth. Evidence has accumulated showing that the long-term goal of the Paris Agreement is by no means extreme [135]. Instead of focusing only on the cost of stricter emission reductions, it is also necessary to consider the costs of the impacts and damage that will be suffered during the time before the climate mitigation measures take effect. Moreover, the “costs” should be considered as “investments”. In general, there is no guarantee that the cost of the damage will be significantly smaller than the costs (investments) required for countermeasures (for example, the amount paid out for storm and flood insurance in Japan in 2018 was JPY 1.6 trillion yen [6]). Of course it is not easy to calculate the monetary value of all damages that affect human life and the ecosystem, but certainly they are significant and should be taken into account.

Regarding No. 2 : If global warming continues on its current path, it is highly likely that it will have severe uncontrollable effects on the Earth's system itself, as well as a devastating impact on both society and economy. Therefore, mitigation measures are essential, and the current desire of the international community is to keep temperature rise below 2°C. However, even if the temperature rise is kept below 2°C, climate change will still have a significant impact. Thus, some degree of adaptation is necessary, and some measures are already being taken. The IPCC Special Report on 1.5°C found that the impact, even when the temperature rise was kept below 2°C, is significantly greater than that of 1.5°C. For this reason, it is preferable to take mitigation/adaptation measures based on a level of 1.5°C, taking into account climate change risks to particularly vulnerable natural ecosystems and humans. In particular, some have suggested the possible use of solar radiation management that lowers the global mean temperature by reflecting solar radiation (geoengineering involves injecting sulphate aerosols into the stratosphere). However, at this stage, we do not consider geo-engineering as an option because its results are highly uncertain, there could be dangerous and unexpected side-effects, and it may be irreversible.

Conclusion

In recent years, it has become clear that anthropogenic climate change has the potential to seriously affect our lives, causing severe weather events that lead to wind and flood damage, and impacting areas such as agriculture and food security, conservation of water resources, coastal areas and oceans, as well as human health. Therefore, by 2050 we need to build a net-zero world (meaning that the net balance of GHG emissions and absorption is zero). In particular, there is a need to significantly reduce the use of fossil fuels in sectors that are sources of large amounts of CO_2. It is not easy to reduce CO_2 because these sectors support many of our socio-economic activities, but there are ongoing initiatives for a net-zero world, such as those being adopted by the central government of Europe, various national and local governments, financial institutions, companies and other stakeholders.

At the same time that global climate change is being experienced, there are also various social and technological developments. These include the rapid deployment of renewable energy, new mobility options based on progress in digitalisation as well as AI and ICT, creation of a sound material-cycle society as a basis for improvements in resource efficiency and handling waste, and increased resilience in adapting to a 2ºC or 1.5ºC rise in temperature. Moreover, policies are being formulated to boost the formation of "circulating and ecological spheres" that contribute to regional revitalisation in Japan by creating independent and decentralised societies, while complementing and supporting the resources in surrounding localities.

Chapter 1 estimated how energy use, material use and GHG emissions might change due to various social changes, using a bottom-up approach. It was assumed that per capita GDP growth will be 0.6% and that the country's overall GDP will remain flat at 2015 levels. For this estimation, two scenarios were used: **a transition scenario (which assumes social transformations in existing social, economic, and infrastructural systems based on international trends, social/domestic issues in Japan, and technological development), and a lock-in scenario (which assumes almost no social transformations due to various circumstances).**

Regarding energy systems in the transition scenario, progress would be made in electrification of the building, transport, and industry sectors. Energy use in all services would also become more efficient. For manufacturing, use of hydrogen would be common for some processes requiring high temperatures in heavy industries. Moreover, a net-zero world would be achieved by supporting people's lives and economic activities through the use of non-fossil fuel energy (mainly renewables).

Even though almost all energy would be supplied by renewables, potential domestic renewable energy could be sufficient because energy demand would be significantly reduced through more efficient use of energy. As a result, the use of CCS could be minimised, and domestic CO_2 storage with high reliability could be used over the long term. Also, the amount of fossil fuel imports could be reduced by about JPY 17 trillion [82] compared to the 2015 level.

On the other hand, in the lock-in scenario, while energy efficiency would improve considerably in households, businesses, transportation, and manufacturing, the energy system is assumed to be based on an extension of current energy technologies. Thus, in this scenario, a net-zero world could be (somewhat forcibly) achieved through the use of CCS and negative emissions technologies in several industrial sectors, and people's lives and economic activities would continue to be supported by fossil fuel use. In addition, to offset the CO_2 emitted from the transportation sector and small factories, it would be necessary to absorb CO_2 from the atmosphere with DACS technology and store a large amount of CO_2 in the ground. In particular, the lock-in scenario could result in reliable domestic CO_2 storage running out within 10 years. Under the lock-in scenario, Japan would also still continue to pay JPY 13 trillion yen each year for fossil fuel imports.

Compared to the lock-in scenario that assumes the extension of current energy technology, the transition scenario incorporates various social changes which would contribute to the improvement of energy security in terms of reducing the dependency on fossil fuels and CO_2 storage. Furthermore, society would be much better off if the massive amount of funds that are currently spent on fossil fuels could be used for other purposes. Moreover, whilst the lock-in scenario would use well-established technology, society would need to use unreliable domestic CO_2 storage which risks large scale releases of GHGs. Also, continued reliance on large-scale imports of fossil fuels would require significant amounts of foreign exchange.

Therefore, we conclude that in order to achieve a net-zero world, Japan should be heading in the direction of the transition scenario. To that end, it is necessary to introduce various measures in all policy areas. A strategy geared towards a net-zero world needs to be positioned as being national, as this cannot be achieved by one organisation alone, and all Japanese stakeholders should cooperate with each other. In particular, when replacing or investing in facilities that can be used over the long term, such as buildings, large-scale power stations and facilities in the industrial sector, it is vital that we have a long-term vision so that industries can respond to social changes that may shift drastically in the future.

Chapter 2 described how our lives would change in a net-zero society under the transition scenario that would transform important societal elements such as existing social systems, economic structures, and infrastructure in response to international trends, domestic social issues, and technological progress. When working to create an independent and decentralised society, people recognise that progress could be made with "Regional Circular and Ecological Spheres," which revitalise regions by complementing and supporting neighbouring regions and local resources. This chapter described specific changes in social norms, lifestyles and industrial activities. The purpose was to promote constructive discussion with many stakeholders and encourage readers to think about how we can build a net-zero world in the future.

At the beginning of the 21st century, the international community has still not reached an agreement on how to take prompt and effective measures against climate change. Of course, it must be highly irritating for future generations, who will be the ones living in a net-zero world, that the current generation was unable to reach this frontier at an earlier stage. They will no doubt wonder why we did not try to realise this dream for all people, and instead carried on pursuing meaningless short-term benefits.

The 2030 target is only one stepping stone. It is not enough for a marathon runner to figure out how to run only 30 km; they must strive to run the full 42,195 km. When developing concrete policies, decision-makers should aim for the finishing line, and set more appropriate and effective policy goals.

Each and every one of us must exhibit a strong willingness to work for the future and we must commit our lives to decisions made now to benefit the whole of human society.

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