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The Institute of Energy Economics, Japan

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¹ Takehiro Iwata, Executive Researcher, Nuclear Energy Group, Electric Power Industry Unit, IEEJ (at the time of writing, currently unaffiliated)

² Atsuo Sagawa, Principal Research Fellow, Energy Security Unit, IEEJ (at the time of writing, currently unaffiliated)

³ This paper was posted by obtaining permission to reproduce a paper presented at the 43rd Japan Society of Energy and Resources Conference.

⁴ Takashi Otsuki, Associate Professor, Yokohama National University (YNU).
(Concurrently serve as Principal Research Fellow, Clean Energy Unit, IEEJ)

IEEJ Outlook 2025 Summary

Energy, Environment and Economy

**How to address the uncertainties
surrounding the energy transition**



**The Institute of
Energy Economics, Japan**

Naoko DOI
Seiya ENDO
Ryou ETOU
Tatsuya HAGITA
Hiroshi HASHIMOTO
Rino HIROSE
Takehiro IWATA
KAN Sichao
Kenji KIMURA
Yoshikazu KOBAYASHI
Ken KOYAMA
Ichiro KUTANI
Tomoko MATSUMOTO
Tetsuo MORIKAWA
Soichi MORIMOTO
Taiju MORIMOTO
Tomoko MURAKAMI
Yu NAGATOMI
Yuto NAKANO
Yasushi NINOMIYA
Junichi OGASAWARA
Kenichi ONISHI
Atsuo SAGAWA
Toshiyuki SAKAMOTO
Yoshiaki SHIBATA
Yoshiaki TAKAHASHI
Kazuki YAMAMOTO
Yukari YAMASHITA
Akira YANAGISAWA

Summary

Global energy supply and demand outlook through 2050

Future primary energy: India and ASEAN drive demand expansion

Our analysis presents two scenarios¹ for global energy supply and demand through 2050. Following current trends, the Reference Scenario projects a 14% increase in global primary energy demand from 2022 to 2050. In contrast, the Advanced Technologies Scenario, which assumes the ambitious deployment of energy and environmental technologies, shows demand will peak by 2030 and fall 6% below 2022 levels by 2050.

Both scenarios indicate declining energy demand in Advanced Economies and China while Emerging and Developing Economies—particularly India and Association of Southeast Asian Nations (ASEAN)—emerge as the primary growth drivers.

Key CO₂ reduction pathways: focus on efficiency, renewables, and CCUS

The Reference Scenario shows global energy-related carbon dioxide (CO₂) emissions plateauing at 32.7 Gt by 2050, as efficiency gains offset demand growth. The Advanced Technologies Scenario projects a significant 62% reduction to 12.9 Gt. The massive reduction requires the convergence of various technologies and mainly relies on three key pillars: energy efficiency improvements, renewable energy expansion (primarily solar photovoltaics and wind), and carbon capture, utilisation and storage (CCUS) deployment.

Energy efficiency improvements could deliver 6.2 Gt-CO₂ in reductions between the scenarios. The greatest potential lies in Emerging and Developing Economies, where implementing proven technologies from Advanced Economies is crucial. This is especially critical for China, India, and ASEAN, where industrial energy consumption is set to surge.

However, we must recognise the lag time between efficiency measures and results—it typically takes over a decade for improvements in new equipment to significantly impact overall stock efficiency for users. Meeting the Advanced Technologies Scenario's 2050 targets require immediate action for efficiency improvement.

Renewable energy shows dramatic growth potential, reaching nearly 60% of global electricity generated in the Advanced Technologies Scenario (excluding hydro). This penetration level means many regions will have variable renewable power generation capacity exceeding their average load, requiring significant investments in grid-scale energy storage, transmission infrastructure, demand response systems integration with existing pumped storage hydro and thermal power generation backup, and so on.

Overall electricity generated is projected to increase 1.6 times (Reference Scenario) to twice (Advanced Technologies Scenario) from 2022 levels by 2050, requiring substantial grid infrastructure expansion.

¹ The scenarios in IEEJ Outlook represent forward-looking projections based on current trends and technology pathways, distinct from backward-planning approaches that start with specific targets (e.g., net zero emissions by 2050) and work backward.

CCUS emerges as a critical technology, capturing 5.1 Gt-CO₂ annually by 2050. While particularly important for power generation, CCUS—alongside hydrogen—becomes essential for hard-to-abate industrial sectors like steel and cement production, where electrification alone cannot achieve complete decarbonisation.

Fossil fuel outlook: significant uncertainty

The scenarios reveal widely divergent paths for fossil fuels. The Reference Scenario shows increased oil and natural gas demand through 2050, while the Advanced Technologies Scenario projects declined by 40% for oil and 7% for natural gas from 2022 levels. Key variables for oil demand are road sector; electric vehicle (EV) penetration, hybrid vehicle uptake, and internal combustion engine (ICE) vehicle efficiency improvement. Natural gas and coal demand largely depends on power generation and industry sectors.

Despite this uncertainty, fossil fuels will remain significant in the global energy mix for decades. Given natural production declines in existing fields, maintaining adequate investment in fossil fuel infrastructure remains critical for energy security, even as we accelerate the clean energy transition.

The critical role of LNG

LNG plays an important role—demand is expected to grow further

Liquefied natural gas (LNG) is expected to play an important role as a realistic solution toward the energy transition—as a pragmatic and reliable energy source—enhancing energy security and contributing to decarbonisation at the same time. In its history, LNG has expanded and demonstrated its role in response to the demands of each era.

Global LNG demand in 2050 is projected to increase by 74% from the present level in the Reference Scenario of the IEEJ Outlook 2025. Even in the Advanced Technology Scenario, global LNG demand is projected to expand until around 2040 and then decline, but demand in 2050 is projected to be at the same level as of today. One of the focal points of increasing demand is Southeast Asia's emerging markets, notably the power generation sector. If the energy efficiency improvements assumed in these scenarios are not realised, LNG demand would increase further.

With the Ukraine crisis increasing the importance of stable energy supply and the emphasis on controlling energy costs under the energy transition, expectations on the important role of LNG in the long-term have been stepping up. The stability of the LNG market should be valued even further. LNG provided the flexibility to respond to the latest energy crisis. The recent instability of supply-demand balances and prices shows the importance of measures to stabilise the market from a long-term perspective.

LNG supply stability requires sustaining investment

The LNG production sector requires additions of 10-20 million-tonne-per-year capacity each year until 2050. These include brand-new LNG production projects, back-fill gas supply development to existing LNG plants, and rejuvenations existing facilities, to meet incremental demand and to supplement reductions of productivity of existing gas fields and processing facilities.

The capacity for which final investment decisions (FIDs) were made during the past three years apparently exceeded the above-mentioned required capacity. However, uncertainty should be noted over realisation and timely implementation of those sanctioned projects.

Long-term agenda toward the stable LNG market

As expectations are high for LNG's role as a viable solution to transition uncertainty, efforts of the LNG market and industry players are necessary to meet these expectations. Companies should make efforts to better manage methane and greenhouse gas (GHG) emissions, to set higher goals, and to disclose appropriate and timely information. It is important to make the entire LNG value chain even cleaner. It is also helpful if the industry can make LNG look more attractive as an investment and financing target.

In order to expand and maintain LNG production in gas producing countries, including North America and Australia, it is important for companies and governments in consuming countries to encourage stabilisation of regulatory aspects and project development in LNG producing countries, as well as to participate in such development.

Medium- to long-term demand aggregation and market development support, including those in emerging markets in Southeast Asia, will lead to expansion of the global LNG market and support for LNG production development.

Issues surrounding LNG production project development

The rapid expansion of LNG supply since the early 2010s has shifted its focus from Qatar to Australia, and then to the United States. While development costs have been on the rise, efforts have been also made to reduce costs such as floating LNG production, small- and medium-scale liquefaction, and modularisation of construction.

Imminent LNG export from the West Coast of North America should be a gamechanger in LNG marine transportation—avoiding transportation bottlenecks, shortening and diversifying transportation routes.

LNG export capacity in the United States is expected to grow steadily over the next few years, although long-term development is uncertain due to the non-free trade agreement (FTA) export authorisation pause and regulatory uncertainty. No FIDs have been made on new LNG production projects in the United States so far in 2024. Some projects under construction or development face court-challenge risks and completion risks. Proactive participation in LNG production projects from an LNG importing country, as well as visible expressions of expectation of increasing LNG supply, would be even more important.

The steady realisation of FIDs over the past few years was driven by long-term commitments by LNG buyers. Portfolio players have become increasingly important in these commitments, while commitments of Japan LNG buyers represent a smaller portion than in the past.

A steady increase of LNG production capacity is expected in the medium term, although construction delays are now the norm. As the increasing supply is likely to be absorbed by markets in Asia and elsewhere, widely touted “oversupply” around the end of the decade is unlikely.

Major LNG export regions with gas resource potential face their respective agenda and challenges. Australia should maintain stable LNG production through further development of gas fields surrounding existing LNG development areas. Qatar is implementing mega expansion projects while incorporating value-chain cleaning measures, and additional

marketing activities from the projects are a point of interest. East Africa with a large resource potential has yet to step up to full-fledged development.

Bottlenecks of LNG transportation and troubles at LNG production plants have impacts on the balance of the market

- Bottlenecks on important shipping routes are likely to be a major obstacle in times of tight supply and demand. It is necessary to develop a long-term LNG transportation strategy.
- Increasing unplanned outages at LNG production facilities are likely to exacerbate supply-demand imbalances, which also necessitate countermeasures with long-term perspectives.

Risk scenarios for energy security

- Securing the necessary amount of energy at an affordable price is essential for society and the economy. However, history has proven that a stable supply of energy can be threatened by a variety of factors. Various risks affect the stable supply of energy, and it is important to correctly understand where the risks lie and their effects, and to take the necessary countermeasures. In the following, we identify and discuss five risks that are considered to be of particular importance in light of today's international energy context.

Risks of fossil fuel underinvestment

- According to the Reference Scenario of the IEEJ Outlook 2025, fossil fuels will still provide 73% of global energy demand in 2050. Asia will become more important in terms of demand regions, while the Middle East and North America (oil and natural gas) and Asia (coal) will have a higher share in supply regions. Stable investments, especially in these supply regions, are of vital importance for the stable supply of fossil fuels. During the long transitional period, fossil fuel supply and demand will become tight if sufficient investments are not made.
- Some argue that no new investment in fossil fuels will be necessary as fossil fuel demand will decline rapidly in the "ideal" carbon neutral society. The risk of fossil fuel underinvestment due to gap between the "ideal world" and reality has become apparent. Without additional investment, oil and natural gas production in 2050 will be drastically reduced to about one-tenth of the current level due to the natural decline of production. It would create a large gap with fossil fuel demand in the real world.
- Tight supply and demand balance for oil and natural gas due to underinvestment is likely to lead to higher prices. A hypothetical 50% increase in oil and natural gas import prices would increase the share of net oil and natural gas imports in the GDP of major Asian importing countries and regions by 1%-3% points. The impact on developing economies such as India and ASEAN is of greater concern, especially.

More serious and diverse geopolitical risks

- Geopolitical risks continue to be a major concern for energy security. As Japan's dependence on the Middle East for crude oil imports reach to historical high 95% in 2023, the geopolitical risks in the Middle East region for Japan are becoming more serious due to the escalation of the situation in Gaza and the deepening conflict between Iran and Israel.
- In addition to the risk of political instability in resource-exporting countries and regions, policy changes in advanced economies have also become a risk factor in recent years. Japan's

coal and LNG imports are highly dependent on advanced economies (81% for coal and 50% for LNG in 2023), but the United States and Australia have introduced policies that increase uncertainty about the future of domestic resource development and exports, reflecting domestic voices concerning climate change issues. This could pose a challenge for market stability over the medium to long term.

Risks of electricity supply instability

- The advancement of digitisation and electrification is increasing society's dependence on electricity. In particular, the deployment of electric vehicles and the expansion of data centres are driving increase of electricity demand. Efforts for decarbonisation will further promote electrification of demand.
- The energy transition is pushing solar photovoltaic and wind power, whose output fluctuates with the weather and the seasons, to become the mainstay of electricity supply. It is necessary to ensure a stable supply of electricity as the share of these variable power sources increases.
- On the electricity supply side, risks of supply stability include supply shortage and price fluctuation of fossil fuels, geopolitical risks, and fluctuations in the output of renewable power sources. On the electricity demand side, there is the risk of an increase in electricity demand and uneven distribution of electricity demand. To address these risks, it will be necessary to secure fossil fuel procurement and baseload power sources such as nuclear, secure supply capacity, and optimise the power system. It is also essential to pursue the best mix for stable supply.

Risks of critical mineral supply

- Manufacturing capacity of some decarbonisation technologies and critical minerals, which are essential for and raw materials for clean energy investments, have high market concentration and are increasingly recognised as a new risk in the energy transition.
- Critical minerals market is smaller and less mature than the fossil fuel market, making it more prone to market dominance, supply-demand imbalances, and the resulting price volatility. The high uncertainty that exists regarding future demand for clean technologies and the fact that it takes about 10 years or more to develop new resources make it difficult to invest in supply source diversification. The intensifying international competition to secure strategic commodities and the heightened resource nationalism should also be taken into account.
- Risk mitigation is possible through combining various technologies with different nature of risks. Development and market creation of those technologies must be promoted.

Increasing risks of cyber-attacks

- Since mid-2010s, the number of critical cyber-attack events has increased significantly worldwide. The energy transition, with its accompanying electrification, digitisation, and network connectivity, has resulted in an increase in the severity of cyber-attacks as a potential risk factor.
- There are diverse patterns of cyber-attacks, with different actors, objectives and targets of attack. In looking at the future international energy situation, cyber-attacks against fundamental energy infrastructure, will become a key issue in energy security. Geopolitical

risks should not be underestimated, and the possibility of weaponisation in the form of threats to energy supply should also be taken into account.

Trends in Solar Power FIP/FIT Auction

Hideaki Obane*

1. Bid capacity exceeded available capacity in eight out of 21 rounds of auction

With the amendment of the law¹ concerning feed-in tariffs (FIT) in April 2017, the selling price of solar power generated as prescribed under FIP/FIT schemes will be determined through auction, and a total of 21 auction rounds have been conducted so far (separate auction sessions were held for the FIT and FIP categories in the 12th to 15th rounds, meaning a total of 25 rounds held if these were added). Details such as the scale of the power generation facility subject to auction, the upper limit of bids, and the publication of the upper limit, have been reviewed several times. In the 21st round of auction held most recently, an upper limit of 9.13 JPY/kWh was set for facilities of 250 kW or more in the FIP category.

Looking at the trends in supply prices from the first auction in September 2017 to the most recent 21st round (Fig. 1), the weighted average price in the first round was 19.64 JPY/kWh, compared to 8.08 JPY/kWh in the 21st round. This represents a halving of the bid price within a period of about seven years (Fig. 1). Moreover, the supply price in the 21st auction was close to 7 JPY/kWh, the target cost for solar power generation in 2025 established by the Calculation Committee for Procurement Prices.

However, looking at the trends in the available capacity and bid capacity in each round (Fig. 2), out of the total 21 auction rounds held to date, the bid capacity exceeded the available capacity only 8 times. In particular, in the 21st round held most recently, the bid capacity was 33.67 MW, making up just 31% of the available capacity (107.00 MW). Furthermore, even when comparing the upper limit bid price with the weighted average of the bid procurement price, the results show that the procurement price remained very close to the upper limit price in many rounds (Fig. 1). Therefore, based on the trends in FIP/FIT auction so far, we can infer that the volume of bids necessary for promoting competition has not been secured, or that the upper limit price that has been set has come close to the limit for power generation companies to secure sufficient profitability.

* Senior Economist, Energy and Economic Analysis Group (EEA), Energy Data and Modelling Center (EDMC), IEEJ

¹ Act on the Partial Revision of the Act on Special Measures Concerning Procurement of Electricity from Renewable Energy Sources by Electricity Utilities

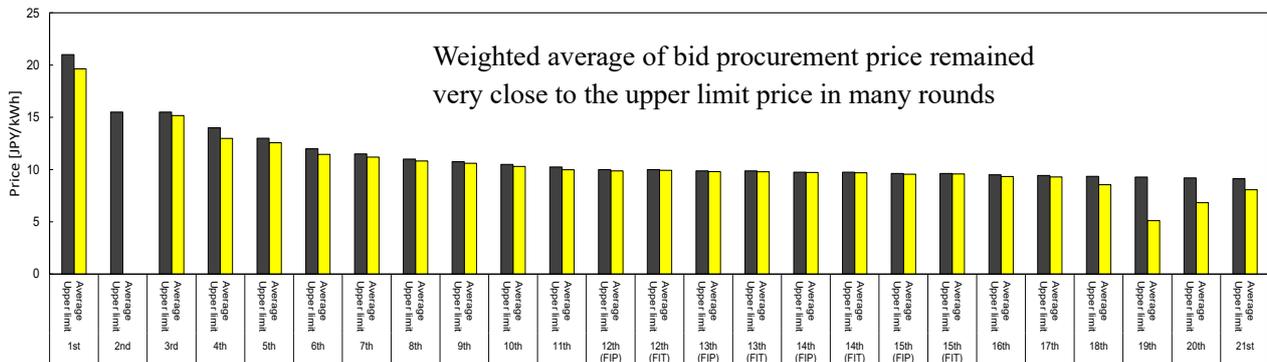


Fig. 1 Trends in supply prices for solar power FIP/FIT auction [JPY/kWh]

(Estimated based on various results of “The Auction System under the FIT Act” of the Organization for Cross-regional Coordination of Transmission Operators, Japan)

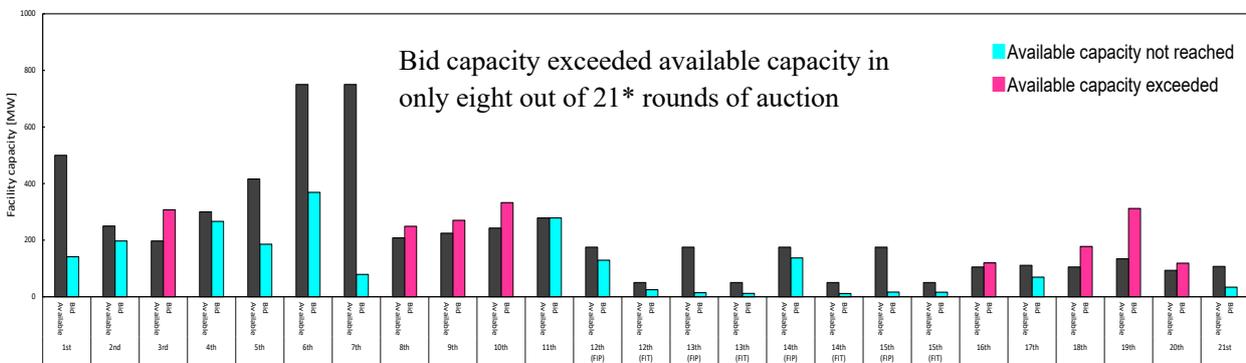


Fig. 1 Bid capacity against available capacity [MW]

(Estimated based on various results of “The Auction System under the FIT Act” of the Organization for Cross-regional Coordination of Transmission Operators, Japan)

* Separate auction sessions were held for the FIT and FIP categories in the 12th to 15th rounds, meaning a total of 25 rounds were held if these were added.

2. Bids at 0.00 JPY/kWh

Of all the rounds of auction conducted to date, the lowest weighted average supply price was 5.11 JPY/kWh in the 19th round. In light of that, looking at the supply prices and power generation facility output of the top eight facilities with the lowest supply prices in the 19th round, it was found that the lowest bid was 0.00 JPY/kWh from Operator A. This in turn pushed down the weighted average of procurement prices in the 19th round. While it is not entirely clear why the operator in question had tendered a bid of 0.00 JPY/kWh, taking into account the views of various online media outlets²⁻³ and other sources, such operators are likely to be supplying electricity directly to electricity consumers through PPA, rather than selling electricity to power transmission and distribution companies at the FIP/FIT supply price.

² Mega Solar Business, “Solar Power Auction Results: Weighted Average Falls to 5 JPY Range, Special Large Output Projects Down to 5,” March 11, 2024

³ Smart Japan, "Project awarded at 0 JPY at 19th round of solar power generation FIT/FIP auction," March 15, 2024

According to the FY2023 business report released by the Japan Electric Power eXchange (JEPX), the annual average price of the wholesale electricity market has been fluctuating significantly over the past three years, from 13.45 JPY/kWh (FY2021) to 20.38 JPY/kWh (FY2022), and then to 10.74 JPY/kWh (FY2023). In addition, the annual average price was particularly high in FY2022 due to soaring fuel costs and tight electricity supply and demand. In such cases where significant fluctuations in wholesale electricity prices are expected, electricity consumers can minimize the uncertainty of expenditure by purchasing electricity directly from solar power generation companies over the long-term. From the perspective of the solar power generation companies, with the upper limit for FIP/FIT bids being lowered to a level of around 9.0 to 9.5 JPY/kWh, there are likely to be cases in which selling electricity through PPA becomes more profitable.

Therefore, although FIP/FIT auction is intended as a system to promote cost reductions for solar power generation through the principles of competition, there are also cases in which power generation companies bid for FIT/FIP in order to acquire certification for their business plans. According to information^{4,5} published by general power transmission and distribution companies, a power generator tariff is imposed on power generation companies to cover the costs required for maintaining and expanding power transmission and distribution facilities, but FIT/FIP power sources that have obtained certification by March 31, 2024, are exempted from this tariff. While it is unclear why a power generation company would place a bid of 0.00 JPY/kWh, at the time of the 19th round of auction, power generation companies would be exempted from the power generator tariff if they acquired certification for their business plans. This creates the incentive for power generators to acquire FIP certification even if they are selling electricity under PPA rather than FIP.

Table 1 Supply prices and power generation facility output of the top eight facilities with the lowest supply prices in the 19th round of auction

Operator	Supply price [JPY/kWh]	Power generation facility output [kW]
Operator A	0.00	19,900
Operator B	4.94	1,990
Operator C	5.00	29,910
Operator D	5.09	1,999
Operator E	5.37	12,000
Operator B	6.00	800
Operator F	6.90	23,000
Operator G	6.90	1,999

⁴ Hokuriku Electric Power Transmission & Distribution Company, "Overview of power generator tariffs (grid-connected power reception service charges)" (https://www.rikuden.co.jp/nw_gkakin/)

⁵ Chugoku Electric Power Transmission & Distribution Co., Inc., "Power Generator Tariffs (Grid-connected Power Reception Service Charges)" (<https://www.energia.co.jp/nw/service/retailer/g-charge/>)

3. Challenges to subsidy-free solar power generation systems.

If a solar power generation company sells electricity through PPA, then that facility alone becomes what is known as an "independent power producer" that does not require renewable energy subsidies. However, it is important to note that this only applies to large-scale facilities at present. For example, if we were to examine the supply prices and power generation facility output for the 19th round of auction (Table 1), the facility with a supply price of 0 JPY/kWh is a large-scale facility with an output of 19.9 MW. Additionally, facilities with a supply price of 6.90 JPY/kWh or less are generally facilities with an output of 1 MW or more.

According to another analysis by the author and others,⁶ with a growing trend of imposing installation restrictions through ordinances aimed at preventing uncontrolled development, there are limited locations available for the installation of ground-mounted photovoltaic generation systems, suggesting that the introduction of solar power generation on buildings with small roof areas will be an important way of expanding solar power generation in the future. On the other hand, based on the "recommendations made by the Calculation Committee for Procurement Prices on procurement prices for FY2024 onward and other details," the system cost of a 500 kW to 1,000 kW solar power generation system installed in 2023 is 147,000 JPY/kW, while that of a 10 kW to 50 kW system is 251,000 JPY/kW. This is a cost difference of about 1.7 times due to the difference in facility scale. Therefore, under the assumption of the large-scale introduction of solar power generation in the move toward carbon neutrality, it will be important to promote cost reductions for small-scale solar power generation systems in the future.

Therefore, in efforts to promote solar power generation through FIP or FIT schemes going forward, there is a need to conduct a detailed analysis of the cost structure of solar power generation based on facility scale and installation location (rooftop or ground-mounted), and to set an appropriate upper limit price in order to reduce the cost of solar power generation and promote its adoption.

⁶ Hideaki Obane, Soichi Morimoto, Yoshiaki Shibata, Takashi Otsuki, "Evaluation of the Potential for Introducing Solar Power Generation in Consideration of Local Ordinances and Building Characteristics," Advisory Committee for Natural Resources and Energy, Committee on Energy Efficiency and Renewable Energy/Electricity and Gas Industry Committee, Subcommittee on Mass Introduction of Renewable Energy and Next-Generation Electricity Networks (67th Meeting)

Voluntary Carbon Credit Trends (April-June 2024)

New Guiding Principles for Carbon Credit Market

Mai Kojima * Soichi Morimoto ** Keita Katayama ***

1. Introduction

This report outlines new principles for the carbon credit market released from April to June 2024. Three actors - namely, private companies, carbon crediting bodies, and governments - have been working to establish a high-quality carbon credit market.

2. Amazon.com, Inc. promotes Abacus standards

Amazon has been working on forest restoration projects as part of its carbon removal initiative.¹ As part of this effort, the company has been developing *Abacus* as a unique framework to verify the quality of carbon offsets related to reforestation and agroforestry. Collaboratively working with Verra, a carbon credit certifier, from 2022, the Abacus label requires “the use of ecologically appropriate restoration systems” and “excludes monoculture plantations.”² According to Reuters, Abacus has been developed as an alternative to the standards of the Integrity Council for the Voluntary Carbon Market (ICVCM), an organization that sets and evaluates quality standards for voluntary carbon credits.³ The Abacus label can be applied for by anyone who meets the requirements of Verra's methodology. However, it is expected to take 2-3 years to obtain the Abacus label since measuring the amount of absorbed carbon will take place after the trees have grown.

Symbiosis, a group jointly formed by Alphabet, Meta, Microsoft, and Salesforce, declared in March 2024 that it would purchase up to 20 million tons of nature-based carbon removal credits by 2030. The group believes that Abacus “incorporates the latest innovations in carbon accounting, including dynamic baselining, robust approaches to leakage mitigation, and pathways for creating durable projects.”⁴

With the development of the Abacus standard, Amazon is expected to be the first company to adopt the standard instead of the ICVCM's carbon offset standard. However, the Bezos Earth Fund remains one of the major funders of ICVCM and has provided \$10 billion for climate change initiatives.⁵ While some are concerned about the proliferation of carbon offset standards established by large technology companies, others point out the significance of the transparency and monitoring of the Abacus label in increasing market integrity.

* Senior Researcher, Climate Change Group, Climate Change and Energy Efficiency Unit, IEEJ

** Senior Researcher, Climate Change Group, Climate Change and Energy Efficiency Unit, IEEJ

*** Researcher, Climate Change Group, Climate Change and Energy Efficiency Unit, IEEJ

¹ Amazon. (2023, November 29). *An update on Amazon's sustainability efforts: Here's what we're doing to aid nature-based solutions and carbon removal.* <https://www.aboutamazon.com/news/sustainability/updates-on-amazons-sustainability-efforts-to-aid-nature-based-solutions-and-carbon-removal>.

² Verified Carbon Standard. (2023, December 15). *PUBLIC CONSULTATION ON ABACUS VCU LABEL.* https://verra.org/wp-content/uploads/2023/11/ABACUS-Public-Consultation_Updated.pdf.

³ Furness, Virginia. (2024, July 4). *Focus: Amazon sidesteps carbon offset standard Bezos helped fund.* Reuters. <https://www.reuters.com/sustainability/amazon-sidesteps-carbon-offset-standard-bezos-helped-fund-2024-07-01/>.

⁴ Strong, Julia. (n.d.). *Introducing Symbiosis.* <https://www.symbiosiscoalition.org/perspectives/introductory-blog>. Retrieved August 16, 2024.

⁵ The Integrity Council for the Voluntary Carbon Market. (n.d.). *Our funders.* <https://icvcm.org/our-funders/>. Retrieved August 16, 2024.

3. ICVCM releases the first carbon credit methodology to meet CCPs

ICVCM announced the first carbon credit methodologies that meet the Core Carbon Principles (CCPs) on June 6, 2024.⁶ The seven carbon crediting methodologies, equivalent to 27 million carbon credits, were approved. Projects are supposed to tackle potent greenhouse gases by capturing methane from landfill sites and by destroying ozone-depleting foams and refrigerant gases from discarded equipment such as refrigerators and air conditioners. Another 27 categories, representing more than 50% of the market, are still under evaluation. The most popular carbon credits, such as renewable energy and REDD+⁷ projects, will be evaluated in a multi-stakeholder working group. The assessments of these methodologies are expected to be completed in the coming months.⁸

The CCP label is a *two tick* system in which CCP-eligible status can only be granted if CCP-approved carbon crediting programs adopt CCP-approved methodologies. Currently, five programs - ACR (American Carbon Registry), ART (Architecture for REDD+ Transactions), CAR (Climate Action Reserve), Gold Standard, and Verra - are CCP-eligible.⁹ These five credit organizations issue 98% of credits in the market. Approval of the methodology has been awaited.

As demand for reliable credits increases, the Claims Code of Practice established by the Voluntary Carbon Markets Integrity Initiative (VCMI) stipulates that carbon credits used by companies must meet the CCPs. Although 90% of credit demand (retirement) is for voluntary purposes,¹⁰ compliance purposes are expected to increase in the future due to the introduction of emissions trading schemes, carbon taxes, CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation), and Nationally Determined Contribution (NDC).

Governments and regulatory agencies are expected to refer to the CCPs as a benchmark for quality standards. In fact, the UK government, the Monetary Authority of Singapore (Transition Credits Coalition; TRACTION), and the U.S. Commodity Futures Trading Commission are considering reflecting the CCPs as international standards in their policies, regulations, guidelines, etc.¹¹ Moreover, Japan also examines the possibility of approving the CORSIA-eligible or CCPs-eligible programs as quality standards in the first phase of the GX-ETS. However, the methodologies that can be accepted so far under GX-ETS are limited to CCU (Carbon capture and utilization), coastal blue carbon, BECCS (Bioenergy with carbon capture and storage), and DACCS (Direct Air Capture with Carbon Storage). In the case of overseas projects, GX League participating companies are required to be involved in the project.¹²

The announcement of ICVCM marks a milestone in the creation of a high-quality credit market, and it will be interesting to see how much of a price premium will be attached to CCP-labeled credits in the future. On the other hand, the market share of the approved methodologies is limited, and it will be important to see if similar approvals

⁶ ICVCM. (2024, June 6). *Integrity Council announces first high-integrity CCP-labelled carbon credits, as assessments continue*. <https://icvcm.org/integrity-council-announces-first-high-integrity-ccp-labelled-carbon-credits-as-assessments-continue/>.

⁷ REDD+ stands for reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests, and enhancement of forest carbon stocks in developing countries

⁸ Assessment status can be checked at the following site: ICVCM. (n.d.). *Assessment Status*. <https://icvcm.org/assessment-status/>. Retrieved January 10, 2025.

⁹ ICVCM. (2024, May 2). *Integrity Council confirms Verra and ART meet its high-integrity benchmark*. <https://icvcm.org/integrity-council-confirms-verra-and-art-meet-its-high-integrity-benchmark/>.

¹⁰ World Bank. (2024). *State and Trends of Carbon Pricing 2024*. <http://hdl.handle.net/10986/41544>.

¹¹ ICVCM. (2024, January 31). *Integrity Council reaches new milestone, assessing 100 carbon credit methodologies against high-integrity benchmark*. <https://icvcm.org/integrity-council-reaches-new-milestone-assessing-100-carbon-credit-methodologies-against-high-integrity-benchmark/>.

¹² Ministry of Economy, Trade and Industry. (2024, April 19) "Guidelines for the Use of Qualified Carbon Credits in the GX-ETS" (in Japanese). <https://gx-league.go.jp/news/20240419/>.

will be granted to methodologies with larger market shares in the future. MSCI analyzed over 4,000 projects and reported that only 18% of all projects are likely to be CCPs-eligible.¹³ 64% of projects that technically remove carbon are likely to meet the standards, while only 8% of renewable energy projects satisfy the requirements. It should be noted that this analysis determines eligibility for CCPs on each project, but the judgment in CCPs will be made on a methodology basis. It should be remembered that credits from non-CCPs-eligible methodologies should not be immediately considered as low quality since there may be some high-quality projects even under the non-CCPs-eligible methodologies.¹⁴

As expected in the analysis above, ICVCM also announced on August 6, 2024, that credits from existing renewable energy methodologies (8 methodologies) would not be able to obtain the CCP label.¹⁵ These credits are estimated to amount to 236 million tons, representing 32% of the voluntary carbon market. The refusal was mostly due to insufficient assessment that projects could not be executed without incentives by credit income (additionality requirements). Renewable energy continues to be an essential climate change solution, and updated methodologies are needed to ensure that the projects meeting additionality are properly evaluated.

4. U.S. Government Announces New Principles for Voluntary Carbon Markets

On May 28, 2024, the U.S. government released new Principles for Responsible Participation in Voluntary Carbon Markets (VCMs).¹⁶ The announcement outlined seven principles for the development of the VCM, which relate to high-integrity supply (Principles 1 and 2), high-integrity demand (Principles 3, 4, and 5), and market integrity (Principles 6 and 7):

1. Carbon credits and the activities that generate them should meet credible atmospheric integrity standards and represent real decarbonization.
2. Credit-generating activities should avoid environmental and social harm and should, where applicable, support co-benefits and transparent and inclusive benefits-sharing.
3. Corporate buyers that use credits should prioritize measurable emissions reductions within their own value chains.
4. Credit users should publicly disclose the nature of purchased and retired credits.
5. Public claims by credit users should accurately reflect the climate impact of retired credits and should only rely on credits that meet high integrity standards.
6. Market participants should contribute to efforts that improve market integrity.
7. Policymakers and market participants should facilitate efficient market participation and seek to lower transaction costs.

¹³ MSCI. (2023, September 20). *Potential Impact of the Core Carbon Principles on the Global Carbon Credit Market*. <https://www.msci.com/www/blog-posts/potential-impact-of-the-core/04582276687>.

¹⁴ MSCI. (2024, June 6). *The First Core Carbon Principles-Qualifying Projects — the VCM Steps on the Gas*. <https://www.msci.com/www/blog-posts/the-first-core-carbon/04528494831#f1>.

¹⁵ ICVCM. (2024, August 6). *Carbon credits from current renewable energy methodologies will not receive high-integrity CCP® label*. <https://icvcm.org/carbon-credits-from-current-renewable-energy-methodologies-will-not-receive-high-integrity-ccp-label/>. In the same announcement a new methodology for the detection and repair of methane leaks in the gas industry was approved.

¹⁶ The White House. (2024, May 28). *FACT SHEET: Biden-Harris Administration Announces New Principles for High-Integrity Voluntary Carbon Markets*. <https://www.whitehouse.gov/briefing-room/statements-releases/2024/05/28/fact-sheet-biden-harris-administration-announces-new-principles-for-high-integrity-voluntary-carbon-markets/>.

These principles aim to increase market certainty for credit buyers and suppliers. Moreover, the principles are consistent with the ICVCM standards, such as additionality, permanence, and prohibition of double counting. Ms. Annette Nazareth, Chair of ICVCM, welcomed the U.S. government's principles, noting that they will reduce greenhouse gas emissions.¹⁷

The announcement by the U.S. government was a ratification of state-level legislation regarding VCM. California, for example, passed a bill on VCM in October 2023.¹⁸ This bill requires the disclosure of information on voluntary carbon offset projects implemented in the state, which needs to be updated at least annually.

Demand for carbon credits is increasing as an influential measure against climate change. In this regard, new principles/regulations/guidelines on carbon credits should be carefully examined.

¹⁷ ICVCM. (2024, May 28). *Integrity Council welcomes US Govt's high-integrity principles for carbon credits*. <https://icvcm.org/integrity-council-welcomes-us-carbon-principles-alignment/>.

¹⁸ California Legislative Information. (2023, September 10). *AB-1305 Voluntary carbon market disclosures*. https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=202320240AB1305.

Estimation of Woody Biomass Energy Supply Curve for Hokkaido

Soichi Morimoto^{*}, Hideaki Obane^{**}, Yoshiaki Shibata^{***}, Takashi Otsuki^{****}

Abstract

In this study, a supply curve of woody biomass energy (fuel log) for Hokkaido was developed. An annual supply potential of fuel log in Hokkaido is estimated to be 2.7 million m³, which is about three times of current supply. However, the regional supply potential varies greatly from -20% to +30% per year compared to the period average since the amount of thinning would decrease in the mid-term. As for supply costs, the proportion of log volume with total revenue exceeding total cost is 71% for Hokkaido as a whole. The profitability of woody biomass energy could be greatly influenced by transportation distance, indicating the importance of local production for local consumption. The annual variation of regional unit supply costs of fuel log was relatively small in the analyzed forests. However, it should be noted that unit supply costs also generally vary from year to year, which is natural, given that only a small portion of the forest is harvested in each year and the cutting age is several decades or longer.

Key words: Woody biomass energy, Hokkaido, Supply potential, Supply cost, Supply curve

1. Preface

Forests account for approximately two-thirds of Japan's land area, and possess multifaceted functions including a mountain disaster prevention function, a soil conservation function, a water resource cultivation function, an environmental conservation function, a timber production function, a cultural function, a biodiversity function and a health and recreation function¹⁾.

As a result of factors including growth in woody biomass power plants, demand for fuel logs is steadily increasing, but in 2022 reliance on imports was high, at 41%. Although the utilization rate of domestic forest residues is also increasing in regard to the quantity of such residues being generated, as of 2021 it remained at around 35%²⁾.

The fuel log supply potential with regard to Japan as a whole and Hokkaido, the subject of this research, was compared by means of the actual supply demand figures for 2022^{3),4)}, the 2030 targets in the Forest and Forestry Basic Plan⁵⁾, the volume of woody biomass power generation anticipated to be introduced in the 6th Strategic Energy Plan⁶⁾ (case of enhanced policy response), and prior research (Table 1).

To begin with, if we look at the Forest and Forestry Basic Plan, when it comes to both the demand forecasts and the supply targets, the actual results for 2022 already exceed the figures assumed for 2030. Furthermore, if we look at the estimates for supply potential, within the three prior research papers assembled here, the Ministry of the Environment's⁷⁾ estimates for potential supply are the largest – when compared against actual supply they represent around eight times the figure for the entire country and

around 11 times the figure for Hokkaido. The corresponding power generation facility capacity is estimated at 3,910 MW for the entire country, which is close to the 6th Strategic Energy Plan's anticipated figure for the volume of woody biomass power generation to be introduced. The supply potential estimated by the Center for Low Carbon Society Strategy, Japan Science and Technology Agency (JST)⁸⁾ is roughly at a level close to the Ministry of the Environment's study. On the other hand, the estimated results from Matsuoka et al.⁹⁾ are at a small level compared to the previous two parties. Additionally, Matsuoka et al. also estimate supply potential that takes profitability into account, and those estimates are around half the estimates for supply potential that does not take profitability into account. The supply potential that takes profitability into account is around the same as the actual supply in Hokkaido's case, and below the actual supply for the country as a whole.

Table 1 Potential supply of fuel log according to prior research, and actual supply and demand etc.

	Item	Nationwide	Hokkaido
Supply	Actual, 2022	10 million m ³	963,000 m ³
	Forest and Forestry Basic Plan 2030	9 million m ³	-
	Ministry of the Environment (corresponding power generation facility capacity)	78 million m ³ (3,910 MW)	11,070,000 m ³ (598 MW)
	JST	60 million m ³	-

^{*} Senior Researcher, Climate Change Group, Climate Change and Energy Efficiency Unit, IEEJ

^{**} Senior Economist, Energy and Economic Analysis Group (EEA), Energy Data and Modelling Center (EDMC), IEEJ

^{***} Senior Research Director, Manager, New Energy System Group, Assistant Director, Clean Energy Unit, IEEJ

^{****} Associate Professor, Yokohama National University (YNU).
(Concurrently serve as Principal Research Fellow, Clean Energy Unit, IEEJ)

	Matsuoka et al. (taking commercial viability into account)	13 million m ³ (6.2 million m ³)	1,999,000 m ³ (1,068,000 m ³)
Demand	Actual, 2002	17 million m ³	1,085,000 m ³
	Forest and Forestry Basic Plan 2030	16 million m ³	-
	6 th Strategic Energy Plan, Power Generation 2030	4,340 MW	-

Note) Actual supply for Hokkaido are estimated by the authors based on statistics⁴⁾

If we examine the estimation methods used in the prior research, the Ministry of the Environment and JST employs a top-down approach according to the proportional division of national and prefectural statistical data, while Matsuoka et al. utilize forest GIS and forest registration and employ a bottom-up approach that estimates the supply potential and supply cost for each minimum unit of forest area, known as a sub-compartment. Forests serve a variety of functions in addition to supplying wood, and there are also many forest stands where felling restrictions are in place, such as nature reserves and forest reserves. Additionally, supply costs are dependent on factors such as choosing the work system according to gradient and undulation, the extraction distance to roads in the vicinity, and the transportation distance to the point of use. A bottom-up approach is suited to accurately taking geographical conditions such as this into account. On the other hand, Matsuoka et al. estimate supply potential by assuming a situation in which the felling volume and growth volume are balanced in the long-term. This ideal state is known as a normal forest, but as discussed below, a current state forest deviates from a normal forest, and the supply potential in the process of leading to a normal forest from a current state forest is not explored. Furthermore, if looked at from the perspective of competition with other energies, it is necessary to build a supply curve that plots the unit supply costs on the vertical axis and the supply potential on the horizontal axis rather than estimating the relationship between supply potential and supply costs as a point, but this has not been carried out in any of the prior research

introduced.

Based on the above, in this research, we attempted to build a supply curve for woody biomass energy that covered Hokkaido, which possesses Japan's largest forested land area, based on a bottom-up approach using forest GIS and forest registration.

2. Data and method

2.1 Commonly used data and forest covered by the analysis

Where forest GIS and forest registration were concerned, for privately-owned forests (general privately-owned forests and Hokkaido-owned forests) we utilized data made publicly available by Hokkaido^{10), 11)}, while for state-owned forests we obtained the data from digital national land information¹²⁾. The forest GIS and forest registration (privately-owned forests only) we obtained were combined, and information such as area, stand age, forest type (planted forest, natural forest, etc.), forest category (the designated condition, such as forest reserve), multilayer classification (single layer forest/multilayer forest) and tree species was prepared for each sub-compartment.

In terms of the forests covered by the analysis, of privately-owned forests and state-owned forests within Hokkaido we limited our analysis to planted, single layer forests, and furthermore, even within that we assumed them to be standing where conceivably, managed forests whose goal is wood production are possible, and we set two zone categories with reference to regional forest plans: forests for producing wood, etc., and water resource cultivation forests (forests that have a function of storing rainwater, preventing sediment runoff and cleaning up water quality). Specifically, when it came to privately-owned forests, of the planted, single layer forests covered we took regular forests to be forests for producing wood, etc., and headwater conservation forests and drought prevention forests to be water resource cultivation forests. When it came to state-owned forests, of the planted, single layer forests, among stands classified as water resource cultivation-type we took regular forests, headwater conservation forests, and drought prevention forests to be water resource cultivation forests. The tree species covered were the main coniferous species found within Hokkaido: Japanese cedar, fir class trees (Todo fir, spruce, Yezo spruce, hiba false arborvitae, Manchurian ash) and larch class trees (pines outside the fir class). Hokkaido's forested land area when arranged based on forest GIS and forest registration is as shown in **Table 2**, and the area of the forests covered in the analysis was 1,096,000 ha, which accounts for 76% of all the planted forests within Hokkaido. Incidentally, because Matsuoka et al. covered all stands of Japanese conifer, Japanese cypress,

akamatsu (Japanese red pine) and kuromatsu (Japanese black pine) and Japanese larch in privately owned forests and state-owned forests, the area of the Hokkaido forests covered in that research was 1,363,000 ha, which is 24% greater than the area covered in this research.

Managed forest patterns such as the number of trees planted, the cutting age, the periodic thinning ratio and the years periodic thinning is carried out were established according to 13 plan areas, according to zone and according to tree species, based on regional forest plans. For the cutting age for water resource cultivation forests, a figure was derived by adding 10 years to the date for forests for producing wood etc. For the yield (yield table) per unit area for each stand age corresponding to the managed forest pattern, we used the Local Yield Table Construction System (LYCS3.3) from Matsumoto et al.¹³⁾ With regard to tree species, for fir class trees we referred to Todo fir yield tables and for larch class trees we referred to Japanese larch yield tables. Additionally, with the LYCS3.3 it is also necessary to input site quality, but because this information was not available, we set an intermediate value of 2.

Table 2 Forest land area (1,000 ha)

Classification		General privately-owned forests	Hokkaido-owned forests	State-owned forests	Total
All regions	Planted forests	652	133	655	1,441
	Natural forests	1,111	460	2,212	3,783
	Treeless land etc.	70	15	200	286
	Total	1,833	608	3,068	5,509
Planted forests covered by the analysis		543	76	477	1,096
Planted forest coverage ratio		83%	57%	73%	76%

2.2 Estimating supply potential

In order to estimate woody biomass energy supply potential, it is necessary to assess the sustainable permissible yield of forests. When forests are in an ideal state, estimating their permissible yields is simple. That is to say, in forests (normal forests) where equal areas of stand exist for each stand age up to the cutting age

(50 years, for example), stands that have reached their cutting ages are clear felled and immediately planted so that it is possible to harvest a certain amount of wood every year for eternity, and the permissible yield across the course of a year at that time is a figure in which the yield at the overall cutting ages for the forest in question is divided by the cutting age. However, because Japan's planted forests were planted intensively during a period of expanded forestation around 1960-1970, the area proportion where the harvest time is around the 50th to 60th year forms a protruding arc in terms of stand age distribution, and this trend is the same in Hokkaido. Consequently, based on the current situation there is a need to assess the permissible yield in the process of leading a current state forest to a normal forest. In this report, we sought this using the simple linear programming shown below, with reference to Tanaka et al.¹⁴⁾ Here, we put constraints to the forest reaching a normal forest after the one felling period, and furthermore assuming that replanting occurs immediately after the regeneration felling.

$$V_{i,j} = X_{i,j} \cdot g_j \quad (1)$$

$$A_{i,j} = A_{i-1,j-1} - X_{i-1,j} \quad (2)$$

$$A_{i,1} = \sum_{j'} X_{i-1,j'} \quad (3)$$

$$\sum_j V_{i,j} = \sum_j V_{i-1,j} \quad (4)$$

$$A_{n+1,j} = \sum_{j'} A_{1,j'} / n \quad (1 \leq j \leq n) \quad (5)$$

$$A_{n+1,j} = 0 \quad (j > n)$$

$$\max \sum_{i,j} V_{i,j} \quad (6)$$

Here, the indices i , ($1 \sim n+1$), j represent period and forest age class, respectively, and n represents plan period. Period and forest age classes were made to be a five-year interval, while n was made the cutting age. The decision variables are $A_{i,j}$ (ha), being the forest area at the beginning of the period; $X_{i,j}$ (ha), being the felling area; and $V_{i,j}$ (m³), being the regeneration felling (clear cutting) volume, and the recent forest area was derived by aggregating the areas of each sub-compartment as prepared at 2.1. The parameter is the timber volume g_j (m³/ha) of the trees (main forests) covered in the regeneration felling per unit of area, as obtained from the yield tables, and was made the same for all sub-compartments. With formula (1) we calculate the regeneration felling volume based on yield tables. Formula (2) is a transition

formula for forest area. Formula (3) shows the implementation of replanting promptly after felling, and formula (4) shows the regeneration felling volume of each period is made constant. Formula (5) shows that a normal forest is reached after the first felling. Under these constraints, with formula (6) the total regeneration felling during the period is maximized. The optimized calculation was implemented for each managed forest case (general privately-owned forests/Hokkaido-owned forests/state-owned forests x plan area x zone x tree species, giving 130 cases in total) as set at 2.1. That is to say, calculations were carried out on the premise that in each managed forest case current state forests are led to normal forests. Incidentally, the optimized calculation does not include the periodic thinning since it is carried out according to a schedule, but the final yield volume includes the periodic thinning volume also. Furthermore, both the regeneration felling and periodic thinning only take the volume of the trunk portion into consideration, and do not include the branch portion.

2.3 Estimating supply costs

The supply cost estimate followed the methods adopted in the prior research^{9), 15)} and covered extraction route creation, periodic thinning and regeneration felling (the felling process, gathering the logs and extraction to roads in the vicinity), transporting the timber to the point of use, replanting and repayments to the forest owners. For replanting costs (including weeding, improvement cutting and nursery thinning), standard costs were sought from the forestry industry's actual results¹⁶⁾ for fiscal 2022, and costs of 1.8 million yen/ha were adopted for Japanese cedar, 1.37 million yen/ha for larch class (Japanese larch) and 1.82 million yen/ha for fir class trees (Todo fir). However, when carrying out replanting a reforestation subsidy (= standard costs x assessment coefficient 1.7 x subsidy rate 0.4) is applied, and so this was also taken into account in this research. For the costs of extraction route creation, the felling process, gathering the logs and extraction to roads in the vicinity, in line with the prior research a working system was established according to the topographical factors (gradient and undulation) of each sub-compartment and the unit cost (yen/ha or yen/m³) of each work was estimated as a function¹⁵⁾ of the topographical factors (gradient, undulation and extraction distance). Here, because thinning is also eligible for a subsidy, in this research also a thinning subsidy (= estimated cost x assessment coefficient 1.7 x subsidy rate 0.4) was applied to sub-compartments with an area of 5 ha or more and a yield volume of 10 m³/ha or more. Additionally, the extraction distance was taken to be the shortest distance in a direct line from a sub-

compartment's center to roads in the vicinity. With regard to the cost of transporting the timber to the point of use, for a unit cost (yen/m³) we referred to the estimated figure (a function of transportation distance) for a 15 t truck from Shirasawa et al.¹⁷⁾ The point of use for timber was considered to be the lumbermill¹⁸⁾ in the vicinity. It is not possible to specify points of use for fuel log in the future but given that local production for local consumption is desirable, the point of use was set as the municipal town hall¹⁹⁾ in the vicinity. The transportation distance should by rights be set as the distance by road, but in this report, we simply made it a figure of 1.5 times the direct distance on a flat surface. For repayments to the forest owners, we referred to in-forest standing timber prices (end of March 2023)²⁰⁾ and set them as 3,878 yen/m³ for Japanese cedar (Tohoku average) and 5,446 yen/m³ for larch class and fir class (Hokkaido/pine).

Using the unit costs (yen/ha or yen/m³) set and estimated for each sub-compartment and work item, total costs were calculated by multiplying the area of each sub-compartment and yield volume, and unit supply costs per volume (yen/m³) were determined by dividing by the yield volume of the cutting ages overall. In addition, in order to consider profitability we also estimated the revenue from selling the timber harvested from each sub-compartment. Timber prices and the production rates for each wood purpose were set as the figures in Hokkaido (and parts of Aomori) in 2022 based on statistics²¹⁾ (**Table 3**).

Table 3 Production rates and prices for timber from regeneration felling

Item		Production rate (%)			Price (1,000 yen/m ³)		
		Japanese cedar	Larch	Fir	Japanese cedar	Larch	Fir
		Timber	Sawing	70	48	42	15.5
Plywood etc.	5		17	20	13.8	13.8	13.8
Woody chip	0		10	13	7.2	7.2	7.2
Total	75		75	75	-	-	-
Fuel log	15		15	15	7.2	7.2	7.2
Loss		10	10	10	-	-	-
Total		100	100	100	-	-	-

Here, Matsuoka et al. set the timber ratio accounted for by the trunk volume at 75%, the ratio of unused materials (fuel log) at

15% and the loss at 10% in the case of both wood from regeneration felling and wood from periodic thinning. It is conceivable that when it comes to wood from periodic thinning the ratio destined for fuel log will be large, but no direct statistics exist. That being the case, in this research, for wood from regeneration felling we assumed the same ratios as Matsuoka et al., and for wood from periodic thinning, we estimated the ratio of timber as 40% and the ratio of fuel log as 50% at levels consistent with Hokkaido's Wood Supply and Demand Results⁴⁾,²²⁾. For the price of fuel log we referred to the figure for wood chip, as did Matsuoka et al.

2.4 Constructing a supply curve

We constructed a fuel log supply curve by integrating the supply potential in 2.2 and the supply costs in 2.3. To that end, we added index k , which designates sub-compartments, to each variable in the yield maximization model we constructed in 2.2 and came up with a model in which the object function changed from the yield maximization during the period to profit maximization (sales – costs). In formula (7), $Reve_k$ and $Cost_k$ are revenue and cost per unit yield, respectively, r is the discount rate and dt is the time increment (five years). Each of the limiting conditions is the same as the model in 2.2. However, where $Cost_k$ is concerned we gave the unit supply cost in the overall cutting ages for each sub-compartment estimated in 2.3, while for $Reve_k$ we set a sufficiently large figure compared to the unit supply cost and made r zero also. As a result of this setting, because ultimately yield maximization is being sought in this model also, the results of the yields for each period correspond to 2.2.

$$\max \sum_{i,j,k} \frac{(Reve_k - Cost_k) \cdot V_{i,j,k}}{(1+r)^{i \cdot dt}} \quad (7)$$

3. Results

3.1 Supply potential

It was estimated that the supply potential of wood (timber and fuel log) for Hokkaido as a whole will be 10.5 million m³/year in 2025, of which 2.7 million m³, or 26%, will be fuel log (Fig. 1). However, because the periodic thinning volume is not constant, the supply potential will change depending on the year. The periodic thinning volume will decline towards 2040 and is increasing subsequently, and this is reflecting the stand age distribution of current state forests. That is to say, because the proportion of young stand ages is low currently, in the medium term the stands that will be the subject of periodic thinning will decline. In the long term the periodic thinning volume will

recover because stands that have undergone regeneration felling and reforestation will grow and become the subject of periodic thinning. It is assumed that the proportion of fuel log that will be derived from periodic thinning will be large, and consequently, the changes over time will be larger than for timber. Additionally, as we will discuss later, in some cases the changes will be even larger for specific regional units.

When the wood supply potential for 2025 is compared to that after normal forests have been reached (Fig. 2), the supply potential arising from regeneration felling increases by 20%. As we have already stated, in current state forests because the ratio of stands that are already reaching their cutting ages is large, if we assume forestation occurs after regeneration felling it will be possible to increase the regeneration felling volume more than it will be after normal forests are achieved. On the other hand, the supply potential arising from periodic thinning declines somewhat.

The supply potential in this research is significantly larger compared to actual felling/production results and cumulative felling plans in regional forest plans (the felling results are for conifers in planted forests; other results are figures for conifers). When compared to the prior research, the reason the supply potential after normal forests is achieved is smaller than estimates by Matsuoka et al. is conceivably due to differences in the forests covered by the analysis, as mentioned in 2.1. On the other hand, in the supply potential estimates from the Ministry of the Environment, the fuel log alone is equivalent to the total wood volume in this research. There are two main causes. In the Ministry of the Environment's estimates, the woody biomass energy reserves are considered to be the sum total of the volume of unused resources generated with regard to the felling volume and the volume of unused resources generated with regard to the annual cumulative increase in forests. Here, the volume of unused resources generated out of the annual cumulative increase is derived by multiplying the annual cumulative increase by 53.8% (national figure), a ratio of unused resources generated that is derived from recent felling volume and timber production volume. However, as is shown in Fig. 2, because the ratio of thinned wood making up the recent felling volume in Hokkaido is large, in this method the estimated volume of unused resources generated with regard to the annual cumulative increase is conceivably a volume that includes a large amount of wood that could by rights be utilized as timber. Additionally, the Ministry of the Environment estimates also cover broadleaf trees, and furthermore, the branch portion is also included as an unused resource, but in this research, we covered the trunk portion only (and 90% extraction ratio). As

was the case with Matsuoka et al., because the price of the branch portion is unclear it is excluded from this research, but in a case where the biomass magnification factor is 1.3, in 2025 the supply potential of fuel log will increase substantially, from 2.7 million m³ to 5.9 million m³.



Fig. 1 Wood supply potential estimation results

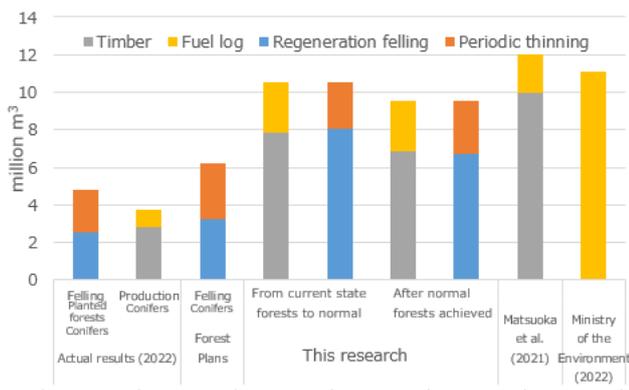


Fig. 2 Comparison of wood supply potential

3.2 Supply costs

The unit supply cost of wood in Hokkaido as a whole was estimated to be 10,600 yen/m³. In terms of items that are major contributors to that cost, repayments to forest owners account for 36%, felling costs 25% and transport costs 17%. In addition, the log volume proportion for sub-compartments where the revenue exceeded the costs was 71%. This is a larger figure than the 53% estimated by Matsuoka et al., but transport cost is conceivably one cause of that. Matsuoka et al. assumed the consolidation points for timber to be cooperative sales locations, and the consolidation points for fuel log to be FIT-certified power plants that were utilizing unused woody material as fuel and were operating as of June 2020, and for many sub-compartments the transportation distance exceeded 100 km. On the other hand, in this research, we set the consolidation points for timber as lumbermills and the consolidation points for fuel log as municipal town halls, which

meant the transportation distance of the volume-weighted average shortened to 45 km for timber and 17 km for fuel log. If, for argument's sake, the cost is calculated for a case where the travel distance for the fuel log was three times that figure (52 km on average), the log volume proportion for sub-compartments where the revenue exceeds the costs declines to 66%, so transportation distance could be described as an important factor on the profitability. However, it is necessary to note that the profitability figure is also dependent to a large extent on repayments to forest owners (in-forest standing timber prices) and assumed sales unit prices for wood. In reality, these prices change as a result of the supply and demand balance for wood and so on. Furthermore, in these estimates, we have not taken caps on afforestation subsidies and periodic thinning subsidies into account, but the reality is that there are limits to such sources of funding.

Looked at in terms of each region (forest plan area), the unit supply cost of wood is between 9,600 yen/m³ and 11,500 yen/m³ and the profit ratio is between 52% and 89% (Fig. 3). In regions where the topographical conditions (gradient and undulation) are comparatively severe, such as West Abashiri, Ishikari Sorachi and Oshima Hiyama, the costs associated with felling (extraction route creation, periodic thinning and regeneration felling) become somewhat large, but in 46% of the sub-compartments covered by the analysis the gradient was less than 15 degrees, and in 98% it was less than 30 degrees, so as a whole Hokkaido's topographical conditions are suited to forestry.

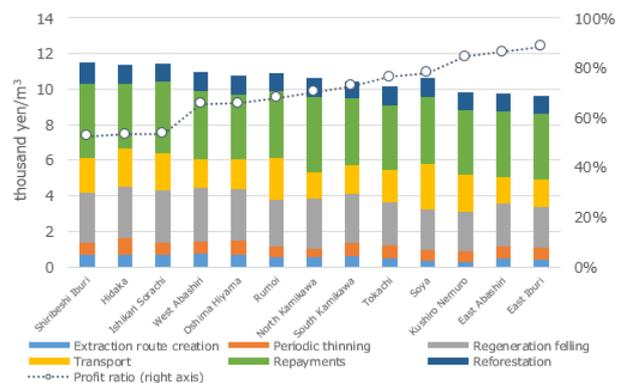


Fig. 3 Unit supply cost of wood by forest plan area

3.3 Supply curve

The supply curve for fuel log (woody biomass energy) in Hokkaido is shown in Fig. 4. Where the horizontal axis is concerned, the right end of the year-by-year supply curve corresponds to the supply potential in the process of leading to a normal forest from a current state forest that was shown in Fig. 1

(the regeneration felling volume is constant but the periodic thinning varies from year to year, and consequently the total supply potential at each point in time does not match). Where the vertical axis is concerned, for the unit supply cost as fuel log, common cost items were sought by apportioning revenue from timber and fuel log, and for transport cost, only the fuel log cost was posted. The fuel log supply curve for Hokkaido as a whole is shifting gently in a shape that is for the most part close to horizontal, and furthermore, although it differs depending on the year, approximately 70% of the supply potential is below the recent fuel log price of 7,200 yen/m³. With regard to the supply potential and unit supply cost of fuel log by region, if we examine the size of the rate of change in each year (minimum value to maximum value) against the average value for 2025-2060 (Fig. 5), the supply potential changes by a range of around -20% to +30% compared to the average value over the period, but the unit supply cost is comparatively stable even when looked at by region. Taking into account the fact that the sub-compartments felled each year are only a small portion of the whole, and that the cutting age is several decades or longer, it would be natural for the unit supply cost to also change each year. However, in the forests covered by our analysis, even when looked at by region there was little variation in the unit supply cost of sub-compartments.

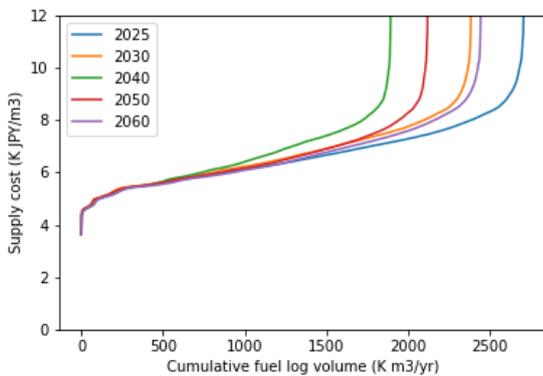


Fig. 4 Fuel log supply curve

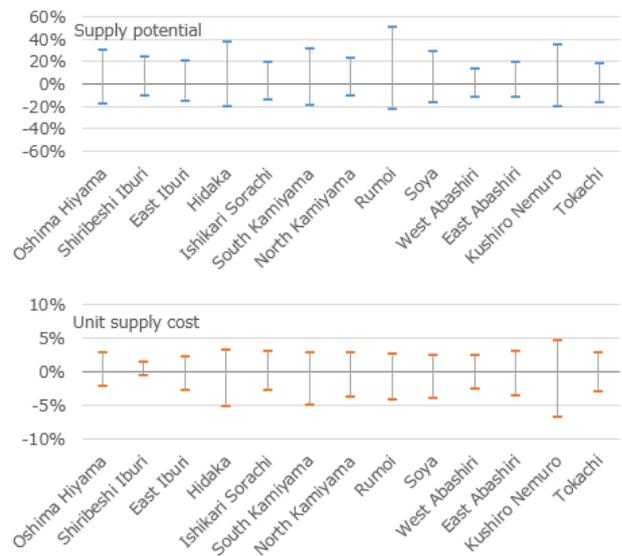


Fig. 5 Size of change of fuel log supply potential and unit supply cost in each year (minimum value to maximum value of the rate of change against the average value for 2025-2060)

4. Conclusions

In this research, we built a supply curve for woody biomass energy (fuel log) that covered Hokkaido. We arrived at three key conclusions. The first is that although the fuel log potential (not including branches) of Hokkaido as a whole is estimated to be up to 2.7 million m³, which equates to around three times the current supply, that may change significantly from year to year. The reason for this is that when the stand age distribution of current state forests is taken into account, in the process of leading to normal forests from current state forests while it is possible to increase the regeneration felling volume more than after normal forest is achieved, the periodic thinning volume will decline in the medium term. Because it is anticipated that the ratio of fuel log derived from periodic thinning will be large compared to that for timber, the change in supply potential over the years will be larger than for timber.

The second conclusion is that local production for local consumption conceivably will exert a major impact on the competitiveness of woody biomass energy. Across Hokkaido as a whole the log volume proportion for sub-compartments where total revenue exceeds total cost (profit rate) was 71%. In this research we set the fuel log consolidation points as municipal town halls and assumed a shortish average transportation distance of 17 km but if, for argument's sake, the cost is calculated for a case where the travel distance for fuel log is three times that figure (52 km on average), the proportion of the supply volume where the revenue exceeds the cost declines to 66%. That said, if considered up to the biomass' consumption stage, there is a

possibility long-distance transport would be justified as a result of economies of scale, such as efficiency improvements resulting from increasing the size of power generation facilities²³).

The third conclusion is that the fuel log unit supply cost may also change each year, not just the fuel log supply potential. Taking into account the fact that the sub-compartments felled each year are only a small portion of the whole, and that the cutting age is several decades or longer, it would be natural for the unit supply cost to also change each year. However, in the forests covered in this research, even when looked at by forest plan area the variation was only around -5% to +5%.

In addition to widening the coverage of the analysis to Japan as a whole, other issues to be addressed in the future include taking into account branches, which were not covered in the estimates in this research; estimating costs for a case in which an upper limit is imposed on the total amount of subsidies; and making timber price assumptions based on future supply and demand.

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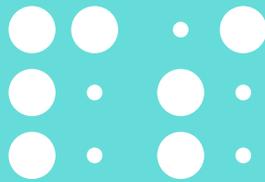
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Editor: Yoshihiko Omori
Publisher: The Institute of Energy Economics, Japan
Inui Bldg., Kachidoki, 13-1,
Kachidoki 1-chome, Chuo-ku, Tokyo
104-0054, Japan
e-mail: report@tky.ieej.or.jp

Please contact the editor for inquiry
e-mail: yoshihiko.omori@tky.ieej.or.jp



The Institute of Energy Economics, Japan