令和３年度エネルギー需給構造高度化対策に関する調査等事業

# エネルギー転換に関する日独エネルギー変革評議会<br>に係る調査

# 報　告　書

2022 年 3 月

一般財団法人日本エネルギー経済研究所

目次

# 第 1 章　日独エネルギー変革評議会の運営

## 1.1 背景

2018 年 7 月に閣議決定された第 5 次エネルギー基本計画では、2030 年に向けて、3E＋S の原則の下、徹底した省エネ、再エネの最大限の導入、火力発電の高効率化といったこれまでの基本的な方針を堅持し、エネルギーミックスの確実な実現を目指す方針を定めた。2050 年に向けては、パリ協定発効に見られる脱炭素化への世界的なモメンタムを踏まえ、エネルギー転換・脱炭素化に向けた挑戦を掲げ、あらゆる選択肢の可能性を追求していくこととした。これを踏まえ、将来的に最適なエネルギーシステムを実現していくために、複線的なシナリオを追求するとの方向を示した。その後 2020 年 10 月に、菅首相は 2050 年のカーボンニュートラル実現を目指すことを宣言した。2050 年のカーボンニュートラル実現はいうまでもなく野心的な目標である。実現に向けた道筋の議論は端緒についたところであるが、国内外の最新情勢を常に把握しつつ、柔軟かつ果敢に挑戦していくことが重要である。

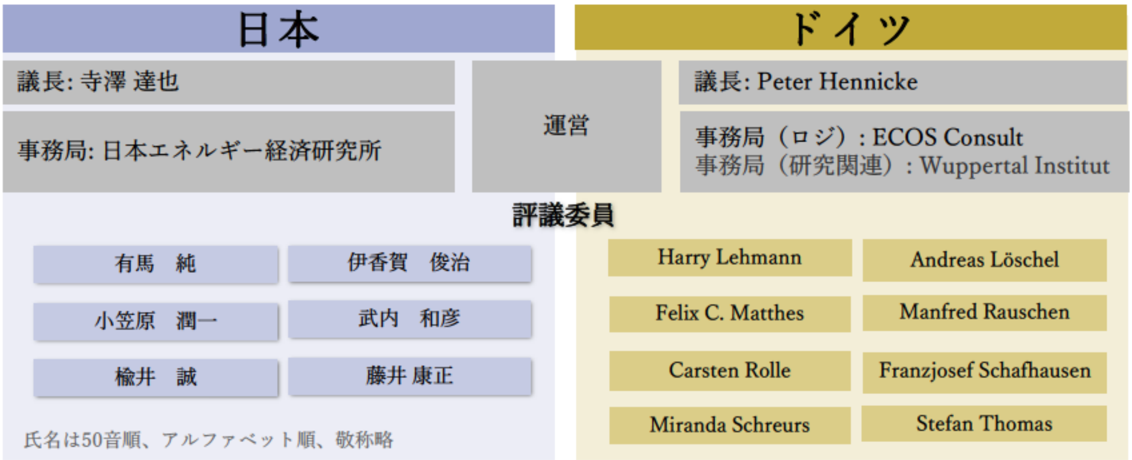
ドイツでは 2010 年に中長期エネルギー供給の在り方を示した「エネルギー・コンセプト」を決定し、現在は、省エネルギーと再生可能エネルギーの利用拡大によって 2050 年までにカーボンニュートラルを達成するという目標を掲げ、エネルギー転換に取り組んでいる。立場の違いはあるが、同様にエネルギー転換に取り組むドイツと二国間協力を進めるべく、資源エネルギー庁では、2016 年に日本及びドイツのエネルギー専門家からなる日独エネルギー変革評議会（日独評議会）を設置し、再生可能エネルギー・省エネルギー等の両国で共通する政策課題を中心に議論を深め、日本のエネルギー政策を企画・立案するうえで必要な情報調査・収集を行ってきた。

令和 2 年度の日独評議会では、エネルギー転換の推進に向けたキーテクノロジーであるデジタル技術や水素、また新型コロナウィルスのエネルギー転換への影響など多岐に渡る議論がなされた。他方、これまでの経緯を踏まえて議論を深化させるべき領域、具体的には脱炭素化が特に難しいと言われている産業の脱炭素化手法の検討や、今後拡大が見込まれる分散型エネルギーシステム実現の課題整理、2050 年カーボンニュートラル実現に向けた道筋の検討などが残されている。こうした議論を引き続き専門家間で深めるとともに、政策担当者間の議論へと発展させていく必要がある。

本調査は、以上のような議論を通じて、日本の長期的なエネルギー転換・脱炭素化に向けた取組の推進に貢献することを目的としている。

## 1.2 評議会の組織

評議会は日独双方の共同議長を筆頭に、それぞれ評議員で構成する。事務局は、日本は日本エネルギー経済研究所が、ドイツは Ecos Consult および Wuppatal Institute for Climate, Environment and Energy が担う。幅広い議論を行う目的から、委員には専門分野が異なる者を選任している。




出所：日本エネルギー経済研究所作成

図 1-1　評議会の構造

表 1-1　評議会のメンバー

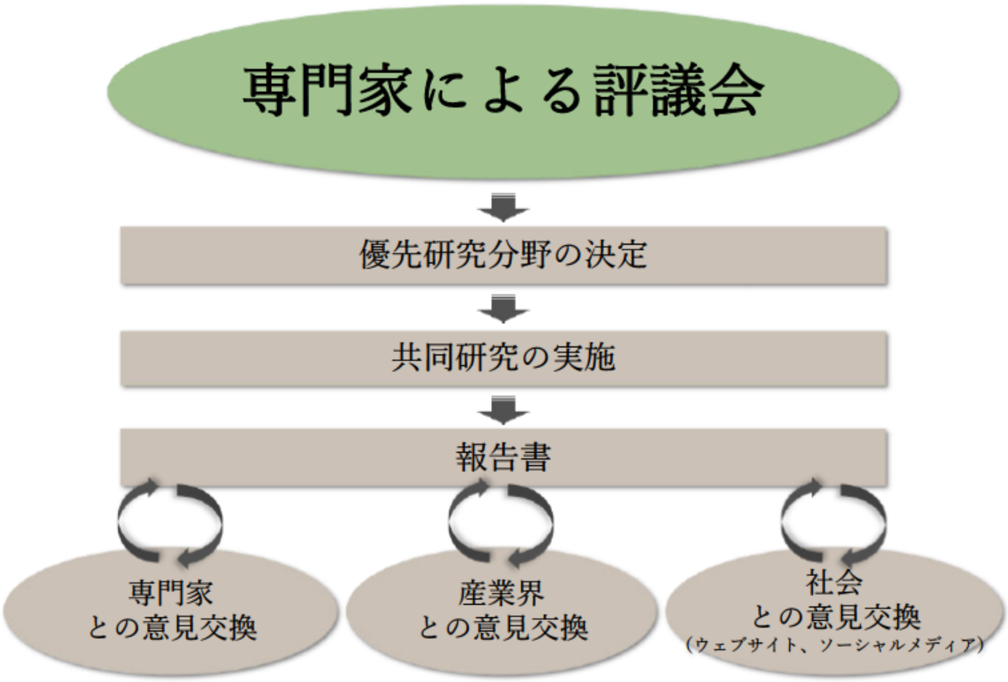
| | |
|---|---|
| **共同議長** | |
| 寺澤　達也 | 日本エネルギー経済研究所 |
| Peter Hennicke | Hennicke Consult |
| **評議委員** | |
| 有馬　純 | 東京大学 |
| 伊香賀　俊治 | 慶応大学 |
| 小笠原　潤一 | 日本エネルギー経済研究所 |
| 武内　和彦 | 地球環境戦略研究機関 |
| 楡井　誠 | 東京大学 |
| 藤井　康正 | 東京大学 |
| Harry Lehmann | PTX Lab – Lausitz |
| Andreas Löschel | University of Münster |
| Felix C. Matthes | Öeko-Institute |
| Manfred Rauschen | Öko-Zentrum NRW |
| Carsten Rolle | Federation of German Industries (BDI) |
| Franzjosef Schafhausen | Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) |
| Miranda Schreurs | Bavarian School of Public Policy; Technical University of Munich |
| Stefan Thomas | Wuppatal Institute for Climate, Environment and Energy |

50 音、アルファベット順。敬称略。

出所：日本エネルギー経済研究所作成

1.3 実施事項とスケジュール

評議会の主な活動は、優先研究分野の特定と関連する議論の実施、報告書の作成、そしてステークホルダーとのコミュニケーションである。




出所：日本エネルギー経済研究所作成

図 1-2　評議会の実施事項

2021 年度は次に挙げる活動を行った。専門家で構成する評議委員会において日独双方が共通に関心を持つ分野に関する議論を行ったことに加え、日独評議会の成果をウェビナーという形で発信、議論を行った。また、産業界や若手研究者との意見交換を行い、より幅広くエネルギー転換に係る議論を実施した。

表 1-2　2021 年度の活動実績

| | 開催時期 | 内容 |
|---|---|---|
| ウェビナー | 2021 年 7 月 | 2020 年度事業の成果報告<br>日独の政策展開の議論 |
| 若手研究者との対話 | 2021 年 9 月 | 若手研究者による関連研究の報告と意見交換 |
| 評議会（その 1） | 2021 年 9 月 | 日独の政策展開の議論<br>2021 年度研究計画の議論 |
| 産業界との対話 | 2021 年 11 月 | 熱電変換素子を題材に技術開発の動向や日独協力の可能性を議論 |
| ウェビナー | 2021 年 11 月 | COP26 の評価<br>長期シナリオに関する議論 |
| 評議会（その２） | 2022 年 2 月 | 日独の政策展開の議論<br>研究成果の議論 |

出所：日本エネルギー経済研究所作成

1.4 研究分野

評議会が選定した優先研究分野は、「エネルギー多消費産業の脱炭素化 – 鉄鋼業 -」「カーボンニュートラルにおける蓄電池の役割」「2050 年に向けた長期シナリオ分析」の 3 つである。研究の目的は、日独両国が互いの経験や取り組みから学び合うことで、今後、それぞれが自国のエネルギー変革の達成を目指すうえで有意義な示唆を得ることにある。そのため、両国が共通して高い関心を持つ分野が選ばれている。

研究は日独の事務局が共同で作成した。また報告書の作成では、評議会における議論の結果も反映した。

**エネルギー多消費産業の脱炭素化 – 鉄鋼産業 -**

（Steel Sector Decarbonization）

鉄鋼やセメント、化学など、製造業の中にはエネルギー消費の電力化と再エネ電力供給による脱炭素の手法が採用しにくく、また鉄鋼産業における高炉法など製造プロセス自身が CO2 排出を伴うなど、技術的に脱炭素化のハードルが高い分野がある。

ドイツと日本には、共に強力な鉄鋼産業が存在し、高品質の製品を安定的且つ競争力のある形で供給することで両国の経済運営に大きく貢献している。しかし、その一方で、両国の鉄鋼産業は、両国の温室効果ガスの排出にも寄与している（多くの温室効果ガスを排出している）。ドイツと日本は、それぞれ 2045 年と 2050 年までのカーボンニュートラル目標を掲げているが、鉄鋼産業は両国でも中核的な役割を果たしている産業であり、両国はその産業を維持しながら排出量を極限まで削減していくという、極めて困難な課題を突き付けられ

ている。本調査では、両国の鉄鋼産業と脱炭素化ロードマップを概観した上で、双方の脱炭素化対応における共通点・相違点を抽出し、それぞれの国に対する政策提言をまとめた。

**カーボンニュートラルにおける蓄電池の役割**

（The role of batteries towards carbon neutrality）

日本、ドイツ共にカーボンニュートラル実現の目標を掲げ、再生可能エネルギーの大幅な導入が進んでいる。太陽光発電、風力発電は、発電出力が気象により変動するため、電力システムの安定的な運用を続けていくには、火力発電の有していた需給調整機能を補完する必要がある。蓄電池は、調整機能の有望な選択肢として期待が大きい。しかし、蓄電池導入には元来の導入目的、蓄電池の所有者の便益がある。

また、将来、住宅用蓄電池や BEV 蓄電池をアグリゲートして、仮想発電所(VPP: Virtual Power Plant)として電力系統の調整力として活用することに大きな期待が寄せられている。アグリゲートされた蓄電池を電力系統で調整力が必要な時に活用するための研究や実証が日本、ドイツで実施されている。

さらにもう 1 点、蓄電池に関して考慮しておく必要がある。蓄電池の寿命には限界があり、二次利用（セカンドライフ）したとしても、最終的にはリサイクルしなくてはならない。日本、ドイツでは BEV の普及拡大に合わせて、蓄電池の二次利用、リサイクルが重要な課題として検討が進められている。本研究では、分散型の蓄電池を系統調整力としての活用するポテンシャル、BEV 蓄電池のリサイクルについて日本、ドイツ両国の現状、今後の可能性、政策動向を調査した。

**2050 年に向けた長期シナリオ分析**

（Long-term scenario analyses up to 2050）

2050 年カーボンニュートラルは日独双方にとって野心的かつ共通の目標である。また、2050 年目標に至る道筋は一つではなく、エネルギーや技術のコスト、インフラの形成状況など各々の環境に応じた適切な選択肢を見出していくことが求められている。

日本とドイツの長期シナリオは異なる背景を基に作成されているが、シナリオの考え方や前提条件などの中には、双方にとって新たな気づきとなる要素も含まれていると考えられる。

そこで両国において各種機関が示しているカーボンニュートラルシナリオの比較を行うことで、両国におけるカーボンニュートラル達成に向けた課題を示し、カーボンニュートラル達成に向けて効率的な方策に向けた示唆を得る。

1.5 評議会等の記録

ここでは、2021 年度に開催した計 2 回の評議会とウェビナーおよびステークホルダーとの対話の議題を整理する。いずれも新型コロナウィルスの影響からリモート形式での開催

となった。

①　ウェビナーその 1（2021 年 7 月 2 日）

| | |
|---|---|
| 16:00 | Welcome by the GJETC Co-chairs |
| 16:10 | Presentation of results from the studies conducted in 2020/2021<br>1. Digitalization and the Energy Transition: Use of digitalization to optimize grid operation utilizing AI and Big Data collected from DERs<br>*Stefan Thomas (WI)*<br>2. CCUS and Hydrogen contributing to decarbonization of energy-intensive industries<br>*Sichao Kan (IEEJ)*<br>3. Energy and climate policy in the post COVID-19 era: Comparative analyses on Germany and Japan<br>*Ichiro Kutani (IEEJ) and Peter Hennicke (WI)*<br><br>Q&A |
| 17:00 | Update of German / Japanese climate strategy and its implications<br>*Prof. Peter Hennicke and Prof. Masakazu Toyoda, Co-Chairs of the GJETC*<br><br>Q&A |
| 17:25 | Closing remarks |

* 時刻は日本時間

② 若手研究者との対話（2021 年 9 月 1 日）

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|---|---|
| **Opening and introduction** | |
| 16:00 | **Opening by the moderator**<br>*Yoshihiko Omori (IEEJ)* |
| 16:05 | **Welcome by the GJETC-chairs**<br>*Tatsuya Terazawa (IEEJ) and Peter Hennicke (WI)* |
| **GJETC at a glance** | |
| 16:15 | **Council structure and format**<br>*Stefan Thomas (WI)*<br>**Current work of the GJETC**<br>*Ichiro Kutani (IEEJ)*<br>**Outlook on future topics**<br>*Peter Hennicke (WI)* |
| **Input by the Young Scientists I:**<br>energy security and sustainable energies – primary from a technical point of view<br>*5-minute-pitches followed by 10 minutes Q&A with the Council Members* | |
| 16:30 | ・ **Towards sustainable energy system – power-to-ammonia technologies as a matchmaker and sector coupling enabler**<br>*Ouda M. Salem (Fraunhofer Institute Solar Energy Systems ISE)*<br>・ **The key aspects of energy security in decarbonization: What has changed?**<br>*Kei Shimogori (IEEJ)*<br>・ **Challenges of Hydrogen Distribution Using Existing Pipelines in Japan**<br>*Nanami Yoshioka (CRIEPI)*<br>・ **The importance of an integrated approach to analyse the power system to increase the renewable energies**<br>*Akihisa Kuriyama (IGES)*<br><br>*moderated by Ichiro Kutani (IEEJ)* |
| 17:30 | Break |

| | | |
|---|---|---|
| **Input by the Young Scientists II:**<br>energy security geopolitics, energy policies and the side-effects of the COVID-19 pandemic from a social scientific point of view<br>*5-minute-pitches followed by 10 minutes Q&A with the Council Members* | | |
| 17:40 | ・ **The path to net-zero: Energy security geopolitics and the making of a hydrogen society**<br>*Julie de los Reyes (Kyoto University)*<br>・ **To switch or have it switched? Automation and delegation of decision rights in the context of energy contract switching**<br>*Gerald Zunker (University of Münster)*<br>・ **Governing Energy Transitions: Phase-outs in Germany and Japan**<br>*Florentine Koppenborg (Technical University of Munich)*<br>・ **Implications of the COVID-19 pandemic for household energy consumption: The stay-at-home orders and energy conservation habits**<br>*Madeline Werthschulte (Leibniz Centre for European Economic Research)*<br><br>*moderated by Stefan Thomas (WI)* | |
| **Discussion on GJETC-topics** | | |
| 18:40 | **Open discussion between the Young Scientists and the Council Members on current and prospective topics**<br>*moderated by Stefan Thomas (WI)* | |
| **Conclusion** | | |
| 19:00 | **Wrap-up of the discussions**<br>*Peter Hennicke (WI)*<br><br>Closing remarks by Peter Hennicke (WI) and Tatsuya Terazawa (IEEJ) | |

* 時刻は日本時間

③　評議会その 1（2021 年 9 月 13 日、14 日）

1 日目

| | |
|---|---|
| 16:30 | Greeting address / video messages<br>*Julia Münch, JDZB*<br>*Technical instructions, ECOS* |
| 16:40 | Words of welcome<br>*Peter Hennicke and Tatsuya Terazawa* |
| 16:50 | General comments on changes in the energy policy in both countries<br>*Tatsuya Terazawa, Peter Hennicke (each 10 min)*<br>Challenges ahead: global implication of COP26 in Glasgow on the energy transition and societal transformation – new perspectives for the GJETC?<br>*Franzjosef Schafhausen + Miranda Schreurs*<br>*Jun Arima + Kazuhiko Takeuchi　(each side 10 minutes max.)*<br>Discussion |
| 18:00 | *Break* |
| 18:15 | The GJETC's study program 2021<br>Study 1:　Decarbonizing energy intensive industry<br>*Presentation of draft outline by Yoshikazu Kobayashi / Stefan Thomas (5 min)*<br>Study 2: Long-term scenario analyses up to 2050<br>*Presentation of draft outline by Hideaki Obane / Naomi Gericke (5 min)*<br>Study 3: Distributed energy systems and the role of batteries<br>*Presentation of draft outline by Toshiya Okamura / Lisa Kolde*<br>*(5 min)*<br>Discussion |
| - 19:30 | Closing Remarks for Day 1 |

* 時刻は日本時間

２日目

| | |
|---|---|
| 16:00 | Selected policy tools for climate neutrality: German/EU initiatives and draft outline of the GJETC topical paper<br>*Input: Peter Hennicke (10 min)* |
| 16:10 | Innovation Partnerships: Technology and Business Field analysis<br>*Input: Stefan Thomas (10 min)*<br>*Discussion* |
| 16:50 | *Break* |
| 17:05 | Suggestions for Innovation Partnerships and Innovation Roundtable<br>*Input: Johanna Schilling (10 min)*<br>*Discussion* |
| 18:00 | Outlook / Coordination of Dates |
| - 18:30 | Expression of thanks and closing remarks by the Co-Chairs<br>*Peter Hennicke*<br>*Tatsuya Terazawa* |

* 時刻は日本時間

④　産業界との対話（2021 年 11 月 5 日）

| | |
|---|---|
| 16.30 | Welcome by the GJETC Co-Chairs:<br>*Tatsuya Terazawa (Chairman & CEO of the Institute of Energy Economics Japan)*<br>*Prof. Peter Hennicke (Former President of the Wuppertal Institute)* |
| 16:35 | Greeting addresses:<br>*Ann-Sophie Weihe-Feijó, Division IK III 5 (Climate Protection and Energy Efficiency), Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU)*<br>*Masanori Kobayashi, Director General, Energy Conservation Department, New Energy and Industrial Technology Development Organization (NEDO)*<br>*Dr. Hartmut Versen, Division IIB2, Federal Ministry for Economic Affairs and Energy (BMWi)* |
| 16:50 | Short summary of the conference “Industrial Waste Heat Use” of the previous day<br>*Patrick Hoffmann, IZES gGmbH* |
| 17:00 | Current research activities of the GJETC on decarbonization of the industry<br>*Dr. Stefan Thomas, Wuppertal Institute, Council Member of the GJETC* |
| 17:05 | Introductory speech: Recent Developments of Thermoelectric Generators for Waste Heat Recovery and their Application<br>*Julian Schwab, Institute of Vehicle Concepts, German Aerospace Center (DLR)* |
| 17:15 | R&D activities and future perspectives for TEGs in Japan<br>*Atsushi Yamamoto, Principal Research Manager of GZR (Global Zero Emission Research Center), AIST (National Institute of Advanced Industrial Science and Technology)* |
| 17:25 | R&D activities and future perspectives for TEGs in Germany:<br>*Dr. Kornelius Nielsch, Leibnitz Institute for Solid State and Material Research (IFW), Dresden* |
| 17:35 | Q&A / Discussion on opportunities and further challenges regarding TEGs |
| 17:55 | Break |

| | |
|---|---|
| 18:05 | R&D project/technology/application examples (Germany):<br>・ Thermoelectric Generators (TEG) for Waste Heat Usage in the Industry: Technologies, Applications, Future Challenges<br>*Dr. Frank Mintus, VDEh Betriebsforschungsinstitut GmbH*<br>・ Thermoelectric generators: previously common approaches, market entry barriers and new approach of Fraunhofer IPM<br>*Dr. Olaf Schäfer-Welsen, Fraunhofer Institute for Physical Measurement Techniques (IPM)*<br>・ Thermoelectric Generators Manufactured by Printed Technology<br>*Andres Rösch, KIT Karlsruhe Institute of Technology* |
| 18:20 | Q&A |
| 18:30 | R&D project/technology/application examples (Japan):<br>・ Sustainable Thermoelectric Module - TEG System with latent heat of condensation recovery<br>*Kentaro Uchida, Director of R&D Department, Hakusan Inc.*<br>・ Introduction of the Self-sustaining Power Supply equipped with the flexible TEG module 'Flexina'<br>*Michio Okajima, Chief Operation Officer, E-ThermoGentek Co., Ltd*<br>・ Efforts to recover waste heat by KELK<br>*Takahiro Murase, General Manager, TEG Business Dept.KELK Ltd.* |
| 18:45 | Q&A |
| 18:55 | Discussion: possible contents for joint R&D projects for further improvement of TEGs (efficiency, costs) or for joint demonstration projects for industrial applications |
| 19:30 | Closure |

⑤　ウェビナーその 2（2021 年 11 月 25 日）

| | |
|---|---|
| 16:30 | **Welcome by the GJETC Co-chairs**<br>*Prof. Tatsuya Terazawa (Chairman & CEO of the Institute of Energy Economics Japan)*<br>*Prof. Peter Hennicke (Former President of the Wuppertal Institute)* |
| 16:35 | **Impressions of the COP 26**<br>*Dr. Karsten Sach (Director-General KI Climate Policy, European and International Policy, Federal Ministry of the Environment, Nature Conservation and Nuclear Safety)*<br>*Prof. Jun Arima (Project Professor for Energy & Environmental Policies Graduate School of Public Policy, University of Tokyo)* |
| 16:50 | **GJETC initial research on key strategies for Germany and Japan towards carbon neutrality**<br>*Prof. Peter Hennicke and Lotte Nawothnig, Wuppertal Institute*<br>*Prof. Tatsuya Terazawa and Dr. Hideaki Obane (Energy and Economic Analysis Group, Energy Data and Modelling Center (EDMC), IEEJ)* |
| 17:25 | **Q&A / Discussion** |
| 17:50 | **Closing remarks** |

* 時刻は日本時間

③　評議会その 2（2022 年 2 月 24 日、25 日）

1 日目

| | |
|---|---|
| 17:00 | Greeting address / video messages<br>*Technical instructions, ECOS*<br>*Julia Münch, JDZB* |
| 17:10 | Words of welcome<br>*Tatsuya Terazawa and Peter Hennicke* |
| 17:20 | Change of government in Japan and Germany: consequences for climate mitigation action and the GJETC<br>*Input by Felix Matthes, (5-10 min) /Jun Arima (5-10 min)*<br>*Discussion/comments by other Council Members (20 min)* |
| | The GJETC's study program 2021/22, part 1 |
| 18:00 | Study 1:　Decarbonizing energy intensive industry<br>*Presentation of final draft by Yoshikazu Kobayashi / Thomas Adisorn (10 min)*<br>*Discussion (25 min)* |
| 18:35 | *Break* |
| 18:45 | Study 2: Long-term scenario analyses up to 2050<br>*Presentation of final draft by Hideaki Obane / Naomi Gericke and Lotte Nawothnig (15 min)*<br>Long-term perspectives of the BDI "Climate Paths 2.0"<br>*Presentation by Carsten Rolle (10 min)*<br>*Q&A and Discussion (25 min)* |
| 19:35 | Closing remarks for day 1 |

* 時刻は日本時間

２日目

| | |
|---|---|
| 16:30 | The GJETC's study program 2021/22, part 2 |
| 16:35 | Welcome by Co-Chair |
| 17:10 | Study 3: The role of batteries towards carbon neutrality<br>*Presentation of final draft by Toshiya Okamura / Lisa Kolde (10 min)*<br>*Discussion (25 min)* |
| 17:05 | Energy and carbon prices and the reduction of fossil fuel subsidies<br>Input: Yumiko Iino / Lotte Nawothnig (10 min)<br>Discussion (10 min) |
| 17:30 | Report on Innovation Roundtable results and follow-up activities<br>*Input: Johanna Schilling (10 min)*<br>*Discussion (also on other topics for further innovation roundtables) (10 min)* |
| 17:50 | *Break* |
| 18:00 | Extending the cooperation of the GJETC beyond March 2022<br>a. General perspectives: First ideas on format, activities and funds<br>*Input: Tatsuya Terazawa (5 min)/ Peter Hennicke (5 min)*<br>b. Proposals on possible study topics for next term<br>*Input: Ichiro Kutani / Stefan Thomas (10 min)*<br>*Discussion (30 min)* |
| 18:50 | Expression of thanks and closing remarks by the Co-Chairs<br>*Peter Hennicke*<br>*Tatsuya Terazawa* |
| 19:00 | End of Day 2 |

* 時刻は日本時間

# 第 2 章　政策課題への効果的な対応策の検討

本章では、日独評議会にて議論された 3 つの研究テーマの成果を概説する。詳細は、付録 2、付録 3 および付録 4 を参照されたい。

## 2.1 エネルギー多消費産業の脱炭素化 – 鉄鋼産業 -

### 2.1.1　背景と目的

ドイツと日本には、共に強力な鉄鋼産業が存在し、高品質の製品を安定的且つ競争力のある形で供給することで両国の経済運営に大きく貢献している。しかし、その一方で、両国の鉄鋼産業は、両国の温室効果ガスの排出にも寄与している（多くの温室効果ガスを排出している）。ドイツと日本は、それぞれ 2045 年と 2050 年までのカーボンニュートラル目標を掲げているが、鉄鋼産業は両国でも中核的な役割を果たしている産業であり、両国はその産業を維持しながら排出量を極限まで削減していくという、極めて困難な課題を突き付けられている。本調査では、両国の鉄鋼産業と脱炭素化ロードマップを概観した上で、双方の脱炭素化対応における共通点・相違点を抽出し、それぞれの国に対する政策提言をまとめた。

### 2.1.2　日独の鉄鋼産業と脱炭素目標

ドイツの鉄鋼産業は、2020 年時点の粗鋼生産量が 3,566 万トン（2020 年時点、世界 7 位）であり、8.7 万人を雇用するドイツにおける主要産業の一つである。生産された製品は、建設部門や自動車、機械などの製造業部門において多く利用されている。国内の需要家から高品質の製品を求められることもあり、粗鋼生産量の約 7 割が、純度の高い製品を生産できる高炉によって生産されている（残りは電炉と一部直接還元製鉄法が用いられている）。高炉を有する製鉄所は国内に 6 か所あるが、その多くが、内陸に位置しており、主として国内向けの製品を生産している。

ドイツは、国全体として 2045 年時点で温室効果ガスの排出を実質ゼロにする目標を掲げている。このため、同国の鉄鋼産業も必然的に同年までに排出量を実質ゼロとすることを求められている。中期的な削減目標としては、Thyssenkrupp が 2030 年までに 2018 年と比べて 30%削減するという目標を掲げている。それよりも高い目標を掲げているのが、Salzgitter であり、同社は 2030 年までに 50%削減するという目標を掲げている。この他、ArcelorMittal は、ドイツだけではなく欧州の製鉄部門全体で、2030 年までに 30%削減するという目標を設定している。具体的な削減手法としては、既存の高炉を用いた製鉄手法から再生可能エネルギーを用いた電炉への振り替え、クリーンな水素による直接還元製鉄、製鉄工程から排出される CO2 の回収・利用（CCU）技術が想定されている。水素については、再生可能エネルギーによる電力で水を電気分解して製造するグリーン水素を主たる供給源とするが、移行期においては一部、化石燃料を原料とし、製造時に発生する CO2 を回収して地下に貯留

して製造するブルー水素を活用するとしている。

次に、日本の鉄鋼産業であるが、粗鋼生産量は 8,319 万トン（2020 年時点、世界 3 位）であり、国内の GDP の 7%を占め、関連産業も含めると実に 30 万人もの雇用を生み出している、日本経済にとっての中核産業の一つである。ドイツ同様、生産された製品の多くは、建設部門と併せて機械や自動車などの製造業部門に多く供給されており、粗鋼生産における高炉生産の比率も約 75%と高い。国内の高炉を有する製鉄所は、太平洋沿岸の産業集積地を中心に 13 か所存在しており、下流産業などの関連産業との有機的な連携体制がとられている。また国内で生産された製品の半分近くが、海外に輸出されているという点もその特徴の一つである。

日本の鉄鋼主要 3 社は、日本全体の排出削減目標と同様、2050 年時点での自社の排出量を実質ゼロにする長期目標を掲げている。中期目標については、日本全体の排出削減目標と企業の目標には違いがみられており、日本全体の排出削減目標が 2013 年比で 46%削減であるのに対し、国内鉄鋼各社の削減目標は 20%～40%となっている。具体的な排出削減策については、ドイツと同様に、水素の活用と CCUS 技術の採用が二本柱となっており、政府と民間が共同でそれらの中核的な技術開発を進めている。前者の技術については、コークスを用いた現在の製鉄方法を代替する技術として、水素を用いた還元製鉄の技術の確立が目指されており、後者の技術については、製鉄プロセスから発生する CO2 を回収して燃料（メタン）へと転換する技術が検討されている。この他、電炉の比率の引き上げやバイオマス燃料の利用、移行期における有効な排出削減策として、次世代コークスの開発やさらなるエネルギー効率の改善といった対応策も進められている。

### 2.1.3　脱炭素に向けた取り組みの比較分析

両国の鉄鋼産業による脱炭素化策には多くの共通点がある。両方とも、長期的なネットゼロ目標を掲げ、中期目標についても明確な数値目標を設定し、具体的な排出削減策の構想を明示している。技術面での水素の活用や CCUS の適用、バイオマス燃料の検討、クリーンな電力を活用した電炉生産比率の引き上げなどは、両国の鉄鋼産業がともに今後の脱炭素化策として検討を進めている。

そうした共通点を多く有する両国の鉄鋼産業であるが、いくつかの相違点もみられる。まず技術開発の進め方であるが、日本の場合には、主要鉄鋼会社 3 社と政府関連機関（NEDO）がタッグを組むことで、個社では十分なリソースを配分することができない大規模かつ革新的な技術開発を進める体制を整えている。民間企業の技術を活用しつつも政府が長期的な支援をコミットすることで、技術開発を進めていく上での財政的な不確実性を大きく低減させている。これに対してドイツにおいては、連邦政府や EU などの資金支援を得つつ基

本的には単独での技術開発を行っている。

また、製鉄工程から発生する CO2 を回収し、CCU 技術を適用して別の製品へと転換する方法を検討しているところは両国の鉄鋼産業に共通しているが、回収した炭素を利用して製造する製品が異なっている。日本の場合はメタンを製造し、自家消費燃料や船舶燃料に用いることが想定されているが、ドイツの場合はプラスチック製品を作ることが想定されている。日本においては、国内のガス供給における脱炭素化策の一つとして合成メタン（メタネーション）の利用が検討されていることが、メタン製造に対する関心を高める大きな理由になっていると考えられる。他方、ドイツでは回収した CO2 が最終的にプラスチック製品として固定され大気に再び放出しないことを重視しているものと考えられる。

水素の供給源についても微妙な違いがみられる。双方の鉄鋼産業においては水素の供給源としてグリーン水素とブルー水素の双方が想定されているが、ドイツの場合には、GHG フットプリントに優れるグリーン水素が重視されている一方で、日本ではコスト優位性のあるブルー水素についてもその供給源として活用していくという方針が取られている。両国における、水素の供給コストと GHG フットプリントのどちらをより重視するのかの差異が、この水素の供給源に対する考え方の違いに表れていると思われる。

さらに、クリーンな電力を活用した電炉比率の引き上げは両国に共通した対応策であるが、そのクリーンな電力の内訳についても違いがある。ドイツの場合には風力や太陽光といった再生可能エネルギーが想定されているのに対し、日本の場合にはそうした再生可能エネルギーに加えて、原子力や水素による発電も想定されている。ドイツにおいては原子力発電のフェーズアウトが決まっている一方で、日本では原子力や水素についても有力な脱炭素化電源として活用していく方針が国のエネルギー基本計画で定められていることが、その違いの背景にある。

この他、両国が独自に検討を進めている技術がある。例えば、ドイツにおいてはバイオエネルギーを活用しその排出された CO2 を回収して地中に貯留する BECCS と呼ばれる技術の利用が想定されている。BECCS は、最終的に大気中の CO2 の量をネットで削減する効果もたらすネガティブ・エミッション技術の一つとして位置づけられており、鉄鋼産業における排出削減が非常に困難であることを踏まえ、その排出量と BECCS で純減させる排出量とを相殺させることで、ネットで排出量をゼロにする効果もたらす。これに対して、日本においては Ferro coke と呼ばれる次世代コークスを活用することで製鉄プロセスから発生する CO2 の量を削減する技術開発が進められている。この技術では、完全に CO2 の排出をゼロにすることはできないため、あくまで移行期における技術となるが、中期的な削減目標を実現する上で有効な削減策として位置づけられている。

2.1.4　政策提言

鉄鋼分野の脱炭素化の観点から、今後のドイツ政府によるエネルギー政策への提言としては、まず革新的な製鉄技術の開発に対する支援が挙げられる。その他にも、製鉄部門の脱炭素化に関わる技術分野としては、特に低コストで水素を製造する電気分解技術を中心とした分野への支援が考えられる。インフラ面においては、電炉による製鉄比率を上げていくうえでは、安定的且つ十分な量のスクラップ鉄が供給できるような物流体制の整備支援が望まれる。社会面では、新たな脱炭素型の製鉄業界へと移行していく際には、それが円滑に進むよう、既存の労働者への新たな形態への職業教育などの労働政策の面での対応も必要となる。そして経済面では脱炭素化への取り組みが、国内の鉄鋼業界の競争力を著しく損なうことのないような国境調整やセーフガード措置などの整備が求められる。この点では、同じく脱炭素化に取り組む国々との国際的な連携も重要となってくる。

日本政府に対する政策提言としては、やはり技術支援に関するものが中心となる。まず水素還元製鉄や CCUS などの革新的な脱炭素化技術の開発、低コストでの水素製造技術の開発が、今後望まれる政策対応の中核的な位置を占める。前者についてはすでに COURSE50 という形での取り組みが進められているが、2050 年時点での実装を意識した明確なスケジュールに基づく技術開発を進めることが重要となろう。水素に関しては、国内のグリーン水素製造技術に加えて、海外からの競争力のある水素の調達や、長期的には原子力エネルギーを活用した水素の供給などの広範な分野にわたる取り組みも必要となる。CCUS については、既に日本企業は CO2 の回収に関しては高い技術を有しているため、今後は回収した CO2 をメタンに転換する CCU 技術の開発にも力を入れていくべきである。CCU では処理しきれない CO2 については地中に貯留する必要が出てくることをふまえ、国内外での安定的な貯留先の確保や、そのために必要となる法制度の整備なども進めていかなければならない。

また、鉄鋼生産の電炉化を支えるクリーンな電力の供給確保についても進めていく必要がある。この点では、当面の目標としての 2030 年時点でのエネルギーミックスの実現が特に重要であり、その上でその先の 2050 年時点での電源のゼロエミッション化を目指したインフラ整備や CCUS 実施体制の確立が、重要な政策課題となってくる。さらに、そうした対応を進める上でのファイナンス面での支援も重要である。鉄鋼産業の脱炭素化に向けた取り組みが市場で適正に評価され、投資を呼び込むことができるような仕組みが必要である。最後に、社会がそうした脱炭素化した製品を適正に評価する土壌を作っていく必要がある。鉄鋼製品の脱炭素化は、その実現に向けて巨額の資金が必要となる一方、製品の品質そのものが大きく変わるわけではない。消費者の目線で見れば、脱炭素化した鉄鋼産業が製造する製品は、品質が変わらないにも関わらず脱炭素コストを上乗せした分だけ高価格なものとなる。そのため、脱炭素の価値が認められないことには、脱炭素技術と脱炭素製品が市

場で広まっていくことは難しい。社会に対する鉄鋼産業の脱炭素化の重要性が明確に認識されるような制度の導入（利用規制など）が必要となろう。

## 2.2 カーボンニュートラルにおける蓄電池の役割

### 2.2.1　背景と目的

日本、ドイツ共にカーボンニュートラル実現の目標を掲げ、再生可能エネルギーの大幅な導入が進んでいる。太陽光発電、風力発電は、発電出力が気象により変動するため、電力システムの安定的な運用を続けていくには、火力発電の有していた需給調整機能を補完する必要がある。蓄電池は、調整機能の有望な選択肢として期待が大きい。しかし、蓄電池導入には元来の導入目的、蓄電池の所有者の便益があり、住宅用蓄電池は住宅用太陽光発電の自家消費を最大化する目的、バッテリー電気自動車（以下 BEV: Battery Electric Vehicle）の所有者にとっては、自動車を走行するための充電が関心事である。

将来、住宅用蓄電池や BEV 蓄電池をアグリゲートして、仮想発電所(VPP: Virtual Power Plant)として電力系統の調整力として活用することに大きな期待が寄せられている。アグリゲートされた蓄電池を電力系統で調整力が必要な時に活用するための研究や実証が日本、ドイツで実施されている。

また、もう 1 点、蓄電池に関して考慮しておく必要がある。蓄電池の寿命には限界があり、二次利用（セカンドライフ）したとしても、最終的にはリサイクルしなくてはならない。日本、ドイツでは BEV の普及拡大に合わせて、蓄電池の二次利用、リサイクルが重要な課題として検討が進められている。本研究では、分散型の蓄電池を系統調整力としての活用するポテンシャル、BEV 蓄電池のリサイクルについて日本、ドイツ両国の現状、今後の可能性、政策動向を調査した。

### 2.2.2　ドイツの蓄電池活用の現状、ポテンシャル

再生可能エネルギーの導入が進み、火力発電所が減少しているドイツでは、電力系統の調整力として 2030 年には 21GWh 規模の蓄電池が必要と予測している。現状では、系統設置大型蓄電池(以下 LSS: Large Storage System）の導入が 0.7GWh、家庭用、商業用等の定置蓄電池（以下それぞれ HSS: Home Storage System、CSS: Commercial Storage System）の導入が 2GWh、その他の蓄電池含めて合計 9GWh が導入されているが、単純計算でも 2030 年までに 12GWh の蓄電池追加が必要になる。

**LSS の現状**

ドイツでは系統調整力の確保を目的として、LSS の導入事例が多い。2019 年末で計 68 基、0.62GWh 導入されている。2019 年の導入ペースは鈍り、9 件、62MWh にとどまっている。LSS 増加で調整力が増え、調整力調達の市場価格は下がっているが、この傾向が続くかどうかは不明である。LSS を設置、所有している事業者は、送配電事業者、発電事業者、

電力小売事業者等で、一次調整力（FCR: Frequency Containment Reserve）：系統周波数変化に追随して出力を変化させる、最も応答時間短い調整力。）に使用されている。

**HSS の現状**

FIT 売価低下で住宅用太陽光発電は自家使用が有利になっている。そのため、住宅太陽光発電設置者を中心に HSS の導入を進めている。HSS の代表的な価格は 700€/kWh、約 70 万円/システムである。HSS を対象にした低率ローン補助が 2018 年に終了しており、現在はグリーン融資を利用することしかできない。

**CSS の現状**

CSS 導入の統計が無いため導入規模の正確な情報は把握しにくいが、導入は進んでいない。CSS 導入の目的は、電力のデマンド料金（ピーク電力に基づく追加料金）の節約のためである。

**分散型蓄電池の調整力活用のポテンシャル**

分散型蓄電池をアグリゲートして系統調整力として活用するニーズは様々で、電圧や周波数等電力系統の安定化だけでなく、停電時のバックアップ電源起動時の電源（ブラックスタート電源）、卸電力市場における価格調整、送配電容量の増強投資の延命策などの用途が考えられる。

ベンチャー企業による新しいビジネスモデル例が数件ある。蓄電池メーカーの SENEC 社は、HSS を電力サービス契約家庭に自ら設置し、卸電力価格が低い時間帯に充電し、電力価格が高騰する時期に活用するモデルや、SONNEN 社が HSS を第 3 者所有モデルとして提供、数千の HSS をアグリゲートして VPP 活用する例がある。このような第 3 者モデルに共通の条件として、「事業者に蓄電池の充電、放電タイミングの決定権がある事」、「蓄電池利用者は、調整力を提供するための蓄電容量に応じて基本料金が得られること、また調整力を提供した充放電量に応じて従量料金を得られるという料金構造がある事」、「蓄電容量の基本料金に応じて、活用できる蓄電容量を保証する事」が指摘されている。

**BEV 導入による電力需要増**

新政権は 2030 年までにドイツ国内で 1,500 万台の BEV 普及を目指している。BEV の普及は電力需要を押し上げ、2030 年には運輸用電力需要が 70TWh、国内総電力需要は 658TWh になると予測している。また、BEV の充電負荷が総負荷の 15%を占めることが懸念されており、充電負荷の管理が重要になる。

**BEV 蓄電池のリユース**

BEV 蓄電池について、自動車メーカーは 10 年または走行距離 15 万 km 超は電池交換を

推奨している。しかしドイツでは自家用車の 10 年超の所有は一般的であり、高額な電池交換費用と日常使用を前提とすれば、メーカーが交換目安としている初期性能の 70%より性能低下した後もそのまま使用を継続する可能性が高いと推測されている。そのため、BEV 廃車時に多くの蓄電池が二次利用可能な状態になると考え難い。また、二次利用のためのコストも大きい。中古リチウムイオン電池は危険物であり、回収、運搬、解体も対策コストがかかる。加えて、BEV 蓄電池の運用設定は自動車メーカーのノウハウであり、二次利用のための性能診断や二次利用向けの再設定は複雑なプロセスになることが指摘されている。残存性能もバラつきが多いことが予想され、小型蓄電池への再利用は困難で再利用可能な場合も大型蓄電池が適しているが、新品の蓄電池価格も下がっている中で、コスト競争力を有するかどうかは判然としない。

**BEV 蓄電池のリサイクルの現状**

BEV 蓄電池に使用されているリチウムイオン電池は、現在 EU ではその他バッテリーに分類され、50%重量のリサイクルしか義務化されていない。リサイクルからの再利用はアルミニウム、鉄、銅などの金属が主な収入で、リチウムイオン電池の原料となるリチウムやコバルトなどの希少金属回収は、潜在価値は認識されているものの実施されていない。

**家庭用蓄電池や BEV 蓄電池の調整力活用に向けた政策課題**

Hidermeier ら欧米の電動モビリティ政策の専門家グループが 2019 年の電動車シンポジウムにおいて BEV 蓄電池の電力系統活用に関する政策提言の研究を発表している。提言では、電力法における貯蔵の概念の明確化、コスト負担の適性化を指摘している。電力グリッド利用時のコスト負担（託送料金負担）が、充電までと放電以降で二重に課金されており、この解消が必要になる。ドイツでは大規模蓄電池の場合は放電以降の消費コストは負担しないことになったが、今後 EU 内でエネルギー貯蔵の定義、規制枠組の改善が予定されている。

**BEV 蓄電池のリサイクル規制**

欧州委員会は新しい蓄電池指令による規制枠組を検討中で、EV 蓄電池分類の新設、EV 蓄電池、充電可能な産業用蓄電池の炭素フットプリント最小要求の設定、2030 年～2035 年の最低リサイクル率要求案を提示している。製造者責任制度に関しても、二次製造者が製造者責任を引継ぐ制度を整備する必要がある。

### 2.2.3　日本の蓄電池の現状、ポテンシャル、政策動向

**LSS の現状、ポテンシャル**

現在、再エネ導入増加に合わせた LSS 整備計画は無いが、導入に向けた取組が進んでいる。参考事例として北海道電力によるメガソーラー、陸上風力発電新規プロジェクトに対す

る大型蓄電池設置要件（2015 年〜）がある。仮にエネルギー基本計画で 2030 年までに増設予定の大型太陽光発電、風力発電プロジェクトの半数に対して北海道電力の場合と同等の LSS 設置が義務付けられたと試算すると、2030 年までに 3.3-5.7GWh 規模の LSS 導入が必要となる。

**HSS の現状、ポテンシャル**

経済産業省は定置用蓄電システム普及拡大検討会(2020-2021)で、コストダウンのための目標価格設定、導入見通しを検討した。HSS の kWh あたり価格は 2019 年度に 2015 年度比▲36%の削減となった（工事費除く）が、更にストレージパリティ 10-15 年を目指し、2030 年度に工事費込み 7 万円/kWh を目標価格として設定しコストダウンを図る。また、2030 年において、新築戸建（21 万戸/年）の 40%、8.4 万戸/年、既築戸建では PV 既設置ストックの 4%、PV 新設ストックの 0.6%の 26 万戸/年に HSS 導入されることを想定し、HSS 合計で 2.4GWh/年の導入、また 2030 年までの累積で約 22GWh の導入見通しを設定した。

**CSS の現状、ポテンシャル**

HSS 同様、経済産業省定置用蓄電システム普及拡大検討会において、kW あたり価格が 2019 年度に 2015 年度比▲45%の削減となった（工事費除く）が、新たに 2030 年において 6 万円/kWh（工事費込み）を目標価格として設定した[1]。また、（1）自治体建物、(2）店舗、(3）病院（歯科、獣医含む）、(4）工場（従業員 30 人規模以上）の 4 分野を CSS の市場として想定し市場ポテンシャルの推計を行った。この結果、CSS においても、2030 年に 0.4GWh/年、また 2030 年までの累計で約 2.4GWh の導入見通しを設定した。

**BEV 蓄電池のリサイクルの現状**

経済産業省と自動車工業会は電動車利用拡大協議会において 2019 年から 2050 年の電動車販売 100%目標、それに伴う電動車蓄電池供給チェーンの整備に関する議論を行っている。電動車リユースワーキングでは、蓄電池の残存性能評価の標準化によるリユースの可能性を議論し、2020 年 6 月には蓄電池性能評価ガイドラインを発表した。ガイドラインでは、初期の電費性能（満充電走行距離）の何割を保持しているかの表示を行うことを推奨する一方、過度の標準化は自動車メーカーの競争の妨げになるとしている。

[1] 定置式蓄電池システム普及拡大検討会　第 4 回、定置式蓄電池システム普及拡大検討会の結果とりまとめ、2021 年 2 月 2 日

**分散型蓄電池の調整力等に活用に関する政策動向**

経済産業省は、分散型リソースを通信制御技術を活用して遠隔指令し、アグリゲートするビジネス（ERAB: Energy Resource Aggregation Business）に資する、実証プロジェクトを実施している。プロジェクトを通じて、通信制御技術を確立し、各種リソースの応動確認、計量の課題確認等が実施された。今後は三次調整力から順次導入拡大を図ると共に、ダイナミック料金による BEV 充電実証が継続される。

**BEV 蓄電池に関する政策動向**

政府は 2021 年 6 月に策定したグリーン成長戦略において、自動車・蓄電池を 14 の重要分野のうちの一つとして位置づけ、2050 年の自動車のライフサイクル全体でのカーボンニュートラル化に向けて、多様な技術の選択肢を追求することとしている。その上で、電動化については、、2035 年までに乗用車新車販売で電動車 100%を目指し、包括的な措置を講じること、また、2030 年までに国内の車載用蓄電池の製造能力を 100GWh まで高めるとともに、スケール化を通じた蓄電池の低価格化、鉱物資源の確保、研究開発・技術実証、リユース・リサイクルの促進やルール整備・標準化等の取組を行うこととしている。

### 2.2.4　政策提言

蓄電池の現状、電力系統の調整力としての活用ポテンシャル、政策動向、BEV 蓄電池のリサイクルについて調査を行った。分散型蓄電池（HSS/CSS や BEV 蓄電池）を電力系統の調整力として活用するためにはいくつかの制度整備が必要になることがわかった。

1）充電時の「消費」としての負担（料金、税等含む）と放電時の「発電」としての負担の重複解消

- 電気事業における「蓄電」事業の明確な定義。
- 分散型蓄電池を供給力や調整力に活用するために必要となる「計量、監視・管理の追加コスト」と「調整力等の系統側に利用する際の価値」がバランスする仕組みの構築。

2）「時間」と「場所」を意識した BEV 充電が重要

- BEV 充電では「時間」（再エネ電気が豊富な時）と「場所」（系統容量に余裕がある場所）を意識し、充電負荷が電力系統に過度なストレスを与えないようにする。
- （再エネなどの）発電状況、電力系統負荷の状況データの公表、それらを反映した時間帯別充電料金
- 発電能力や系統容量を反映した充電ステーションの整備計画
- スマート充電テクノロジーやスマート充電インフラの活用

3) BEV 蓄電池の再利用やリサイクルには制度の整備が必要

・ 電池の追跡・管理、製造方法や成分の表示（ラベリング）制度を整備。
・ 蓄電池の状態や残存寿命を把握する基準を整備。
・ 再利用後の製造者責任を明確にするための議論が必要。

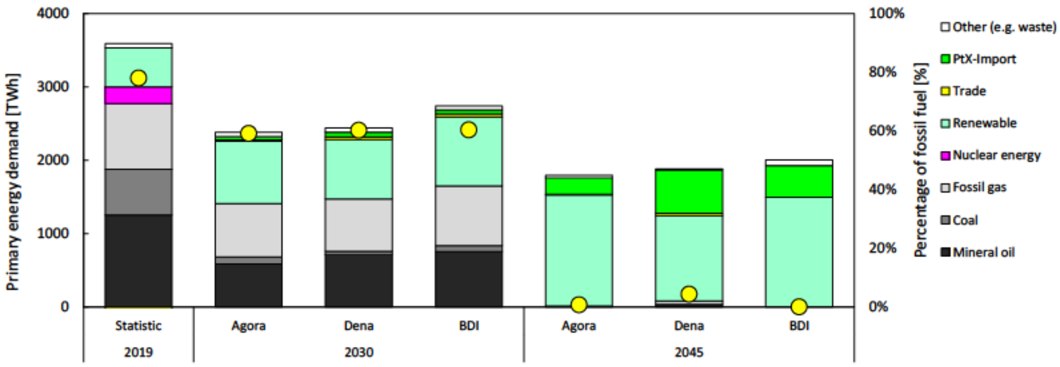
## 2.3 2050 年に向けた長期シナリオ分析

### 2.3.1 背景と目的

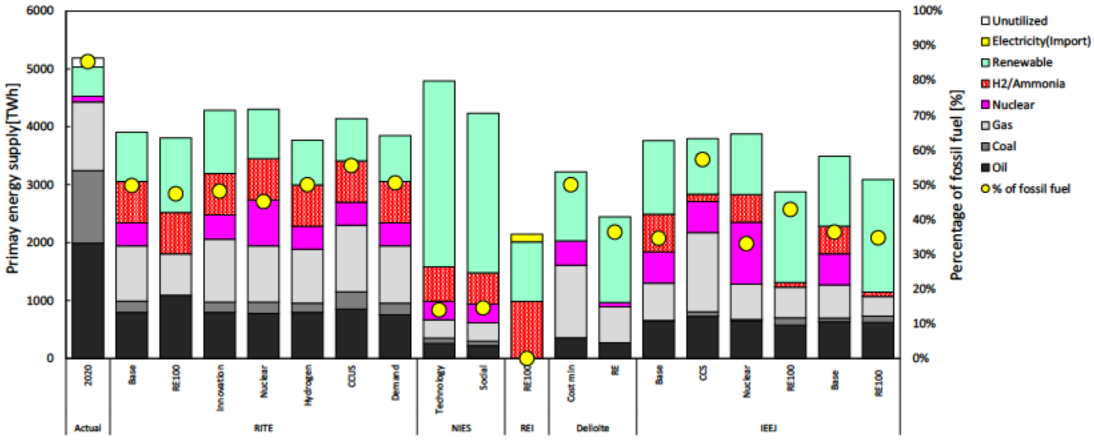
2050 年カーボンニュートラルは日独双方にとって野心的かつ共通の目標である。また、2050 年目標に至る道筋は一つではなく、エネルギーや技術のコスト、インフラの形成状況など各々の環境に応じた適切な選択肢を見出していくことが求められている。日本とドイツの長期シナリオは異なる背景を基に作成されているが、シナリオの考え方や前提条件などの中には、双方にとって新たな気づきとなる要素も含まれていると考えられる。そこで両国において各種機関が示しているカーボンニュートラルシナリオの比較を行い、両国におけるカーボンニュートラル達成に向けた課題を示し、カーボンニュートラル達成に向けて効率的な方策に向けた示唆を得る。

### 2.3.2 分析対象とする長期シナリオ

本分析で比較対象とするシナリオは、日本の基本政策分科会にて提示された RITE、国立環境研究所、自然エネルギー財団、デロイト、IEEJ の 5 機関によるシナリオ、およびドイツの 2045 年以降を評価対象としている Agora、Dena、BDI、UBA の 4 機関によるシナリオとした。いずれのシナリオも、2045 年もしくは 2050 年までに各国でカーボンニュートラルを達成することを前提にしたバックキャスト型のモデルによって作成されている。

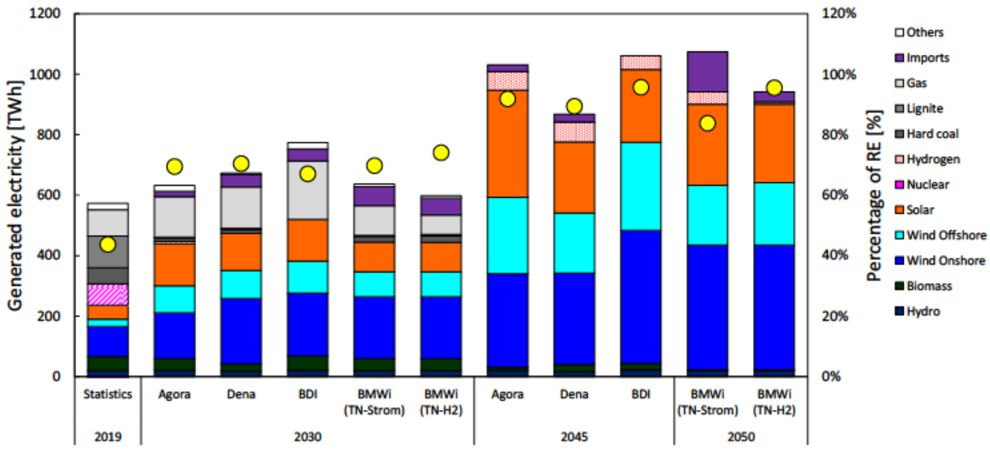



(A) ドイツ

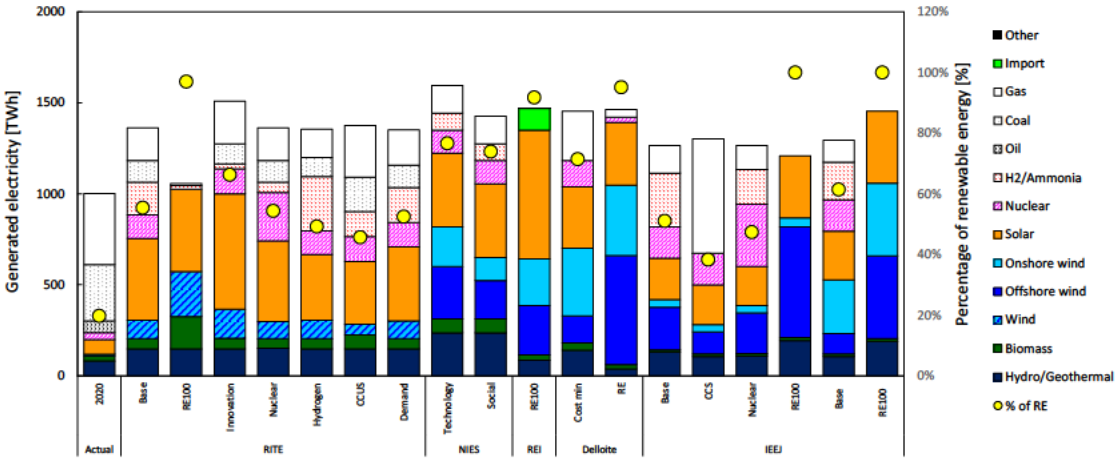



(B) 日本

図 1 一次エネルギー供給・需要[TWh]




(A) ドイツ




(B) 日本

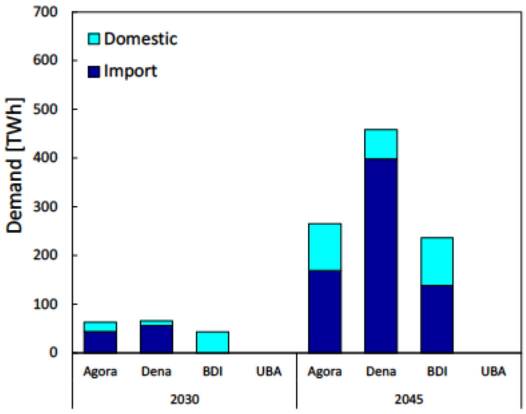
図 2 発電電力量[TWh]

### 2.3.3　ドイツの長期シナリオ

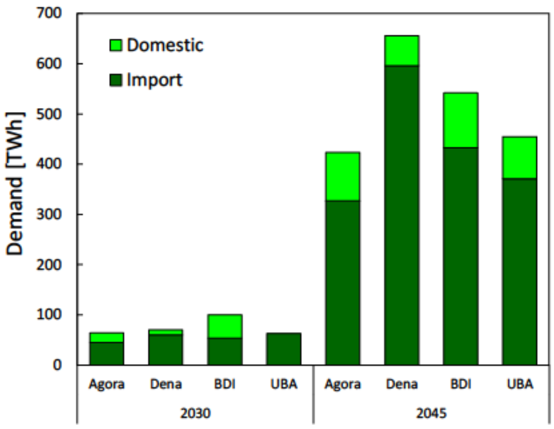
ドイツのシナリオ分析結果の一番の特徴は、2045 年の一次エネルギー供給における化石燃料供給の比率はほぼゼロとなり、発電電力量のほぼ 100%が再生可能エネルギーもしくはグリーン水素によって賄われている点である。なお、原子力は前提条件の段階で考慮されず、CCS は一部の産業部門のみに使用する想定となっている。他方で、ドイツのシナリオは、他国からのグリーン水素や合成水素に依拠しており、グリーン水素は 0-398 TWh、合成燃料は 327-596 TWh が輸入となっている。ドイツのシナリオの最終エネルギー消費（2045 年）は 1,500TWh 程度であるため、ドイツのエネルギー供給におけるグリーン水素および合成燃料輸入の依存性は高い。Dena の分析においては、各地域のうち東欧（52-73EUR/MWh）や、北アフリカ（54-69EUR/MWh）からのパイプライン輸入が相対的に安い想定となっており、グリーン水素は近隣諸国からの輸入を想定していると考えられる。しかし、他国においても同様に温室効果ガスの削減が求められる中で、最終エネルギー消費の半分以上に相当するグリーン水素や合成水素を調達できるかは不透明であり、これらの輸入が実現しなかった場合におけるシナリオは示されていない。

ドイツの 2045 年における再生可能エネルギーの導入量は、太陽光発電 130-385 GW、陸上風力: 124-180 GW、洋上風力: 50-70 GW となっており、太陽光発電と陸上風力が中心となっている。ドイツにおいては、乱開発を防止するための土地利用計画が州毎に行われており、再生可能エネルギーが設置可能な場所はこの土地利用計画によって定められる。2020 年においては、太陽光発電 5 GW、陸上風力 1 GW が導入されたが、2045 年までに前述した導入量を実現するためには、現在の年間導入量の 1-2 倍（太陽光発電）、もしくは 5-7 倍（陸上風力）の導入が必要となる。そのため、各シナリオの累積導入量と土地利用計画によって定められる設置可能量の整合性の確認を行い、必要に応じて土地利用計画を見直すことが必要となりうる。

電気自動車やヒートポンプなどの電化に関わる需要側のエネルギー技術は、モデルの前提条件として強制的に導入されることとなっており、想定した需要側のエネルギー技術の導入量に基づき最終エネルギー消費が決定される。ドイツの最終エネルギー消費は、2019 年の約 2,500 TWh から約 40%減の約 1,500 TWh となっており、この実現のために電化や省エネ技術の導入が前提となっている。




(A) グリーン水素




(B) 合成燃料

図 3 ドイツにおける燃料需要

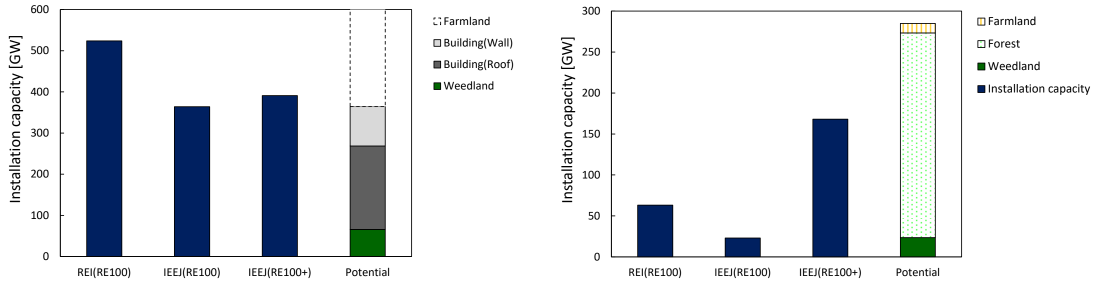
2.3.4 日本の長期シナリオ

日本のシナリオでは、一部の機関を除き、様々な技術の利用を想定した多様なシナリオが示されている。ドイツのように再生可能エネルギーのみで電力供給の全てを賄うことを前提としたシナリオもいくつか存在するが、再生可能エネルギーに加えて、原子力発電や CCS 付き火力発電、アンモニア発電、水素発電の活用が想定されている。発電電力量に占める再生可能エネルギーの比率は 40%-100%であり、対象とした 5 機関の全 18 シナリオのうち 13 シナリオでは、既存および計画中の原子力は全て再稼働する結果となっている。また、RE100 シナリオにおいては、太陽光発電 364-524GW、陸上風力 23-168 GW、洋上風力 88 -205 GW が導入される結果となっているが、この導入量を達成するためには、農地や森林などといった、農業との競合や自然環境への影響が懸念されるような場所にまで発電設備を設置する必要性が高まる。例えば、環境省の導入ポテンシャル評価によれば、建物や耕作放棄地の太陽光発電の導入ポテンシャルは 381 GW であるが、500 GW を超える太陽光発電の導入量を実現しようとする場合、100 GW 分の営農型太陽光発電を導入する必要性が生じる。このように、再生可能エネルギー100%で発電電力量の全てを賄うシナリオはモデル上では解が存在するものの、実際にこのシナリオを現実のものとする場合には、自然環境への影響や社会的受容性について慎重に考慮される必要がある。

また、18 シナリオのうち、自然エネルギー財団と Deloitte を除く 15 シナリオでは、最終エネルギー消費において一定の化石燃料消費が含まれている。これらの化石燃料消費によって生じた CO2 は CCS によって回収されることとなるが、現状日本において CCS がどの程度貯留可能かは十分明らかになっていない。特に CCS の依存量が高いシナリオにおいては、その実現性は CCS による CO2 の貯留ポテンシャルにも依存することに留意が必要である。

RITE、国環研、IEEJ のシナリオでは、既存の発電技術に加えて、水素やアンモニア発電

によって一部電力供給が賄われている。日本においては、ドイツと異なり隣国からのパイプライン輸入が容易でない中で、水素やアンモニアなどを安価でかつ安定的に供給する方策を検討することが重要となる。




(A) 太陽光発電　　　　(B) 陸上風力

図 4 日本の RE100 シナリオにおける導入量と設置場所別の導入ポテンシャルの比較

### 2.3.5 政策提言

このように、日本とドイツはともに 2045/50 年までにカーボンニュートラルを実現するという野心的な目標を掲げているが、各々の特徴に応じてカーボンニュートラルを前提とした場合のシナリオの特徴は異なる。ドイツでは「脱原発」を先行的に進めており、多くのシナリオが再エネの 100%近くとなる結果を示しているが、一次エネルギー供給の多くをグリーン水素と合成燃料の輸入に頼っており、エネルギー安全保障の観点では課題は残る。これら燃料の輸入に依存しない代替シナリオが示されていない中で、ドイツのように特定の技術のみに依存したシナリオを目指すことは必ずしも適切ではない。

日本においては、カーボンニュートラルに向けて、特定のシナリオのみに依拠せず、幅広い方策を念頭に置いておくことが重要である。

# 第 3 章　日本のエネルギー政策への提言

ここでは、ドイツの産業政策をエネルギー・環境を中心に整理し、そのうえで日本のエネルギー産業の競争力強化に向けた検討を行う。

## 3.1　ドイツの産業政策

ドイツでは 2021 年 9 月に総選挙が行われ、Scholz 政権が誕生した。従来、産業およびエネルギー政策は連邦経済・エネルギー省（BMWi）が担っていたが、気候政策を所掌に加えることで新たに連邦経済・気候行動省（BMWk：英語名 Federal Ministry for Economic Affair and Climate Action）が組織された。本項執筆時点で確認できる範囲では、BMWi と BMWk[2] の産業政策に大きな違いは見られない。

ドイツの産業が引き続き世界の中で競争力を維持し続けるためには、イノベーションの発揮に適したビジネス環境と熟練労働者の供給の維持が必要としている。連邦経済・気候行動省（BMWk）は今後のドイツ産業でカギとなる分野と技術を特定しているが[3]、機械・プラントエンジニアリング技術、電子工学、生産技術、材料技術、バイオ・ナノテク、ヘルスケア・医療技術、モビリティ・物流、ICT などと並んで、エネルギー・環境技術を挙げている。特に ICT 技術については、あらゆる分野でより複雑な製品やサービスを生み出すことに貢献するとしている。エネルギー・環境およびモビリティ分野で重視している技術を以下に示す。

- 高効率発電技術
- 再生可能エネルギー技術（風力、地熱）
- 省エネルギー技術
- 衛星画像処理、利用技術
- 建物の省エネ改築技術
- 廃棄物管理、リサイクル、リユース技術
- 電動車技術
- 衛星を利用したナビゲーション技術

気候変動問題との関係では、産業は気候変動や省エネ・省資源、再エネ拡大における経済

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[2] BMWk, 2022 年 3 月アクセス, https://www.bmwi.de/Redaktion/EN/Dossier/modern-industry-policy.html

[3] BMWk, 2022 年 3 月アクセス, https://www.bmwi.de/Redaktion/DE/Textsammlungen/Industrie/leitmaerkte-mit-zukunftspotential.html

への影響という点で重要な役割を果たすとしている。これは、環境保護は産業にとってコストであると同時に、新たなビジネス機会ともなるためである。BMWk は、ドイツ産業のなかでは機械やプラント、計測設備、電気設備に係る産業はグリーン技術の輸出によって、第三国の環境問題解決に重要な貢献を成してきたとする。

ドイツ政府は産業に対して、政府が定める温室効果ガス削減目標への貢献を求めている。Climate Check と称する企業の気候リスクを評価する体系を整備し、企業による脱炭素行動を支援している。他方、同時に、気候政策が進展するなか、ドイツ産業が不利になるような市場の歪みは正すべき、あるいは産業や投資のカーボンリーケージを回避する必要があるとも指摘している。こうした考えの発露の一つが、欧州で議論されている炭素国境調整メカニズム（CBAM：Carbon Border Adjustment Mechanism）であろう。

政策のスタンスでは、市場を重視した技術中立なものを志向している。経済効率性への配慮が必要であり、そのためには企業間の競争を促す必要があるためである。また、科学的な発見をすばやく商業的な技術や製品、サービスへと展開するイノベーションを企業に促すことを目的とした「High-tech Strategy」を 2014 年に定めた。具体的には、産学間のコミュニケーションや連携を強化し、また中小企業や研究グループによる国際貢献を含む活動を支援する[4]。

原材料とエネルギーはあらゆる産業にとって不可欠な物資であり、この供給について次のような方針を定めている。原材料については、供給の輸入依存度が高いため、安定供給を確保すると同時に、効率的な利用や再利用を促す。また、化石資源が次第に制限されていくため、代替としてバイオマス資源にも注目している。

エネルギーでは、化石燃料を再生可能エネルギーに転換していく。ドイツは世界の中でも電気などエネルギーのコストが高い国であることから、産業の競争力を維持するためには公租課税の一部免除が必要としている。

ドイツの産業競争力強化に向けて、2015 年に BMWi（当時）を含む 17 の組織・団体が参加する”Future of Industry” Alliance（未来の産業同盟）が組織された。デジタル化やプラットフォームビジネス、グローバル化、気候変動問題、他国との競争などドイツ産業界を取り巻く環境が大きく変化するなか、同盟は多様なステークホルダー間の対話と議論を通じた、政策形成に対するインプットの場として機能している。また同盟は、カンファレンスを主催するほか、幾つかのモデル地域で同様な対話の場を構築することで地方の産業と

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[4] BMWk, 2022 年 3 月アクセス, https://www.bmwi.de/Redaktion/EN/Artikel/Technology/high-tech-strategy-for-germany.html

BMWk を結びつける役割も担っている。

### 3.2　日本のエネルギー産業競争力強化に向けて

ここでは、評議会での議論や 3 つの研究テーマの成果を踏まえ、日本のエネルギー産業の競争力強化に向けて取り得る施策を示す。まず、3 つの共同研究の結果として導き出された政策提言を簡単に整理する（詳細は第 2 章参照願いたい）。

| | |
|---|---|
| エネルギー多消費産業の脱炭素化<br>– 鉄鋼産業 - | ・ 引き続き、水素還元製鉄や CCUS など革新的な脱炭素化技術や低コストでの水素製造技術の開発が重要。<br>・ 海外から競争力のある水素の調達や、長期的には原子力を活用した水素供給など広範な取り組みが必要。<br>・ 鉄鋼生産の電炉化を支えるクリーンな電力の供給確保を進めていくことが必要。<br>・ 鉄鋼産業の脱炭素化に向けた取り組みが市場で適正に評価され投資を呼び込むことができる仕組みが必要。 |
| カーボンニュートラルにおける蓄電池の役割 | ・ 充電時の「消費」としての負担（料金、税等含む）と放電時の「発電」としての負担の重複解消<br>・ 「時間」と「場所」を意識した BEV 充電が重要<br>・ 車載蓄電池の再利用やリサイクルには制度の整備が必要 |
| 2050 年に向けた<br>長期シナリオ分析 | ・ 代替シナリオがない中で、特定の技術のみに依存したシナリオを目指すことは必ずしも適切ではない。<br>・ 特定のシナリオのみに依拠せず、幅広い方策を念頭に置いておくことが重要 |

評議会では共同研究の成果に加え、両国が検討する最新政策や昨今のエネルギー情勢を題材にさらに発展した議論が行われた。例えば次のようなものである。

- 1 年以上続くエネルギー価格の高騰は国民や産業に大きな影響。エネルギー転換の過程でエネルギー価格が上昇することは産業界にとって大きな課題。
- エネルギー転換ではエネルギーインフラの大きな作り直しが必要。既存インフラの有効活用という点で合成燃料の意義がある。
- ロシアによるウクライナ侵攻はドイツを含む欧州のエネルギー安全保障にとって非常に大きな意味を持っており、供給安定性をより強く志向する方向。ドイツではこれまで積極に取り組んでき脱原発、脱石炭の工程を遅らせる可能性もある。
- クリーンエネルギー技術に要する重要鉱物のセキュリティの意義がますます高まるのではないか。

- 日独ともに産業競争力を維持･向上することが重要であり、エネルギー転換はそれを支えるものとすべき。ただし、国によって取り得るアプローチは異なるのではないか。
- 社会的受容性は重要であり、多くの分析で過小評価されているのではないか。
- 国際的なクレジットの取引が活発になれば、水素やアンモニアなどクリーンエネルギーの貿易が不要となり得るのではないか。

こうした評議会での議論を踏まえ、以下の提言を行う。

① 省エネルギー、省資源の強化

2050 年のカーボンニュートラル目標の実現に向けては様々な投資が必要であり、したがって追加コストが発生する。エネルギー・資源によっては、世界の需給が緊張することで価格が上昇することも起こり得る。多くの場合、エネルギー・資源の価格上昇を管理することは不可能であり、それが発生した場合には受け入れざるを得ない。そのため、こうしたリスクを減じるためには、同じ付加価値を生み出すために要するエネルギー・資源の消費量を削減することが求められる。

日本の産業はこれまで長く省エネルギーに取り組んできた結果、世界有数の高効率を達成してきたが、これを更に高めていくことが期待される。こうした技術は日本の産業競争力強化に貢献することはもちろん、技術そのものが競争力のある輸出財となる。政府は引き続き、適切な規制によって産業の省エネルギー・省資源活動を誘引し、また企業では負うことが難しい高リスクな技術開発投資を支援することが考えられる。

ここで、省エネルギー・省資源技術は企業の競争力を左右する場合があり、そのために優れた技術が企業内で秘匿され、またその結果として市場獲得の時機を逸し、あるいは異なる技術との融合の機会が失われたりする可能性が考えられる。一義的には、技術開発は自由な企業活動や競争のもとで最適化されることが望ましいものの、技術交流のプラットフォーム提供など、政府による関与の余地が残されているかもしれない。

② 化石エネルギーが持つ地政学的リスクからの脱却

世界が 1970 年代の二度に渡る石油危機で経験した化石エネルギーが持つ地政学的リスクは、今も存在する。2021 年の冬以降、様々な要因によって世界のエネルギー価格の高騰が続いている。加えて、2022 年 2 月のロシアによるウクライナ侵攻では、欧州の天然ガス供給におけるロシア依存のリスクを浮き彫りになったほか、西側諸国による強力な対露経済制裁は将来の石油および天然ガス供給に暗い影を落としている。

日本は化石エネルギー供給を輸入に依存せざるを得ず、また化石エネルギーの多くがリスクのある国に賦存している。そのため、化石エネルギーの利用が続く限り日本はその地政学的リスクから無縁ではいられない。産業の持続的な成長にはエネルギーの安定かつ低廉な供給が不可欠であり、したがって化石エネルギーがもつ地政学的なリスクから徐々に脱

却していくことが望ましい。理想的には、供給するエネルギーを国産に切り替えていくことでリスクを切り離していくことが望まれ、選択肢には再生可能エネルギーや、再生可能エネルギー由来のグリーン水素/アンモニア、原子力がある。これらの活用は気候変動政策と整合するものでもあり、合理的な選択であるといえる。

ただし、これらの普及拡大には国民の理解が不可欠である。例えば、原子力では国民の意見が分かれているほか、再生可能エネルギーについても野放図な開発に対して厳しい目が向けられるようになっている。政府には、適切に開発を行うための環境整備とともに、国民がエネルギー・環境問題に関する正しい知識に基づいて理性的な判断を行うための情報提供や教育を行うことが求められる。

③　エネルギー・資源輸入の確保

化石エネルギー利用からの脱却は理想的だが、現実には長い移行期間を要し、当面は利用を続けざるを得ない。化石エネルギーの輸入確保に向けては、輸入相手国や輸入ルートの多様化がカギとなる。なかでも、Quad を構成する米国や豪州からの輸入は、供給量のみならず安全保障の点でも重要な意味を持つと考えられる。

脱炭素にむけては水素やアンモニアの利用も期待されているが、国内にはそれらの製造に足る十分な再生可能エネルギー資源や化石エネルギー資源、CO2 貯留ポテンシャルが少ないと考えられるため、輸入も要すると見られる。この場合、エネルギーはクリーンになるが、引き続き地政学的リスクに晒されることになる。そのため多様化をキーワードとした対策や、輸入相手国としての米国や豪州の重要性は化石エネルギーのそれと同じである。

脱炭素を目指す上では、クリーン技術の製造に要する鉱物資源の確保も重要である。一部の鉱物は生産や精製を限られた国に依存しており、化石エネルギー以上にリスクの高い状態にある。政府は、重要鉱物の権益確保や、重要鉱物の省資源や代替材料の開発を支援等をすべきであろう。

④　既存インフラの有効活用による移行コストの低減

脱炭素の過程ではエネルギーや産業のインフラを大きく作り直す必要の生じることが考えられるが、当然のことながら、インフラの再構築はコスト増となって産業の競争力を減じる要因の一つとなる。ここで、クリーン水素と回収した炭素から製造する合成燃料は、性状は石油製品やメタンと同じであり、したがって現在あるインフラや産業プロセスをそのまま利用することができる。すなわち、脱炭素に要するインフラ投資を大きく減らすことができる可能性がある。

合成燃料は水素と炭素から合成するというプロセスから、例えば水素を直接利用する場合と比較して総合効率が劣らざるを得ず、また現時点では高コストである。しかし、今後技術革新によって合成燃料のコストが下がれば、インフラ投資の抑制というメリットによって、利用する分野によっては総コストを引き下げる可能性があると考えられる。

⑤　産業のカーボンリーケージ回避

脱炭素に向けた規制の強化やエネルギーを含む気候対策コストの高まりは、産業のカーボンリーケージを招く懸念がある。世界の多くの国は脱炭素に向けて踏み出すことを決めたが、その歩調は一律でなく、したがって気候対策コストの安い国は常に存在することになる。新型コロナウィルスの蔓延によってサプライチェーンの破断を経験した企業のなかには国内回帰の動きをみせる例もあるが、気候対策コストが企業の国際競争力を脅かす水準になれば、国外への移転という経営判断も出てくるだろう。こうした動きを防ぐ手立てとして、ドイツが行っているように、国際競争に晒される産業に対して気候対策コストの免除や、気候対策コストをオフセットするような減免税を講じることが考えられる。

欧州が検討している炭素国境調整メカニズム（CBAM）に類するものも産業のカーボンリーケージの抑制を念頭においているが、国によって異なる産業の特性を踏まえた検討が必要である。

⑥　アジアの低・脱炭素支援による競争力の高いサプライチェーン構築

日本の産業は、アジア諸国に素材の調達源や製造拠点を多く持っている。脱炭素を進めていくなかでは、製品のライフサイクルで GHG 排出量を削減することが求められ、したがって製品サプライチェーンの一部であるアジア諸国の低・脱炭素化も、日本の産業の炭素競争力を左右する要因となる。類似の構図は、欧州とアフリカ、あるいは北米と中南米に見ることができる。そのため、アジアの炭素集約度をアフリカや中南米のそれよりも小さくすることができれば、日本企業は欧州や北米の企業に対してカーボンフットプリントの競争力を高めることができる。

また、日本製品の販路としてのアジア諸国の炭素排出規制が強化されていけば、日本の気候対策コストの高まりはアジアでは相対的に緩和され、日本製品の価格競争力を維持することにも寄与する。

現実には、エネルギー消費の増加が著しく、また所得水準もそれほど高くないアジア諸国の低・脱炭素化は容易でない。しかし、アジア諸国の低・脱炭素化支援は日本企業への裨益のみならず、国際エネルギー市場の安定化という利益も期待できるものであり、積極的に追及すべき政策である。

⑦　国際的なクレジットメカニズムの制度化による削減コストの低減

脱炭素に向けては、先ずは国内での対策を行うべきである。国内での対策投資の多くは、日本経済の一部として国内に残るためである。しかし、限界削減費用が他国との比較で過度なものとなるようであれば、国外から安価な排出権を購入することも経済合理的な選択肢となり得る。こうした選択肢を得る意味で、国際的なクレジットメカニズムの制度化を進めることが考えられる。

ただし、パリ協定の下では途上国自身も削減目標を持つことから、取引可能な排出権は多くはない可能性がある。

## 付録１．日独エネルギー変革評議会の記録

日独エネルギー変革評議会（その１）
2021 年 9 月 13 日、14 日

### General comments on changes in the energy policy in both countries

- 日本は 2021 年 7 月にエネルギー基本計画の案を取り纏め、パブリックコメントを募集中である。COP26 までに閣議決定する予定となっている。2030 年の削減目標は 26%から 46%に強化し、2050 年にカーボンニュートラル（CN）とする目標。2050 年の CN に向けた具体的な方策は定まっていない。非電力部門を極力電力化し、電力化の出来ない部分は水素やバイオマス、CCUS を利用することになるだろう。電力の脱炭素化には再エネ、原子力、CCUS を活用することになる。需要側では、製造プロセスの革新や車両の電動化、建物のゼロエミッション化が必要。供給側では、再エネの最大限の導入、原子力の見通しの不透明さ、水素供給チェーンの構築が課題となる。水素キャリアとしてアンモニアにも期待がある。2050 年 CN に向けては様々な課題があり、ドイツから学べることがあると期待している。
- EU では 2021 年 7 月に、2030 年の削減目標達成に向けた措置を包括的に取りまとめた Fit for 55 を発表した。EU 経済の競争力に配慮した炭素国境調整メカニズム（CBAM: Carbon Border Adjustment Mechanism）や、脱炭素のインセンティブとしての欧州排出量取引市場（EU-ETS: Emission Trading System）などが整理されている。ドイツでは 2 つの大きな変化があった。2021 年 3 月に出された判決では、次世代の自由を制限してはならない、コストを次世代に付け回してはならい、とした。次いで、2030 年の CO2 削減目標が 55%から 65%に引き上げられ、2040 年 85%削減という目標が定められた。Climate Change Act ではセクター別に拘束力のある削減目標を定めたことが特徴である。目標達成状況のモニタリングと対策へのフィードバックを講じることが明記された。これまで遅れていた交通セクターでの対策が進むことを期待。ドイツでは間もなく選挙があるが、新政権はこれをフォローアップしなければならない。

### Challenges ahead: global implication of COP26 in Glasgow on the energy transition and societal transformation – new perspectives for the GJETC?

ドイツの見方

- 近年は激甚気象が多発している。従来は気候変動を疑う議論もあったが、いまでは多くの国が CN を宣言するまでになった。
- EU では 2050 年 CN を目標に、中間段階の削減目標を引き上げることが行われている。目標達成に必要な再エネの導入拡大を図るうえでは、社会の受容性が影響。

- ドイツでは 2021 年 6 月に Climate Change Act が成立し、各州でも独自の法令や目標を定めている。
- 国際的には米国はパリ協定に復帰した。米国の気候特使が活発に動いており、対中国でも対話を実施している。
- GJETC は学術的な知見をもって第三国での貢献が可能。

日本の見方 1

- COP26 を楽観していない。アジア地域では CO2 排出量が拡大する見込みで、全世界で 2050 年 CN 目標を共有するのは困難ではないか。
- SDG の優先順位をみると、アジアでは気候変動の優先順位は相対的に低い。気候変動対策に対する willingness to pay をみると、米国の調査結果では月 10 ドルの負担にでさえ反対する結果であった。これは CN に必要な炭素価格に全く届かない。途上国の willingness to pay はさらに低いだろう。
- CBAM は発展途上国が強く反対しており、貿易紛争になりかねない。
- 米や英は中国に削減目標の強化を働きかけているが、今のところ結果は芳しくない。COP26 において 1.5℃で合意するのは困難ではないか。
- アジア諸国では低廉なエネルギーに対する要請が高く、SDGs のなかで気候対策の優先順も高くない。やり方を間違えると、先進国と途上国の対立に発展しかねない。
- 中国はグリーン製品と非グリーン製品の両方を売ることができる良い立場にあるのではないか。
- 世界の脱炭素化にとって安価な中国製 PV パネルは不可欠であるが、ウイグルの人権問題とどう折り合いをつけるのかが課題。
- 途上国が受け入れ可能な低脱炭素オプションを提示することが重要ではないか。

日本の見方 2

- 日本は欧州と比べて食生活という点で有利（日本食の方が低炭素)。例えば地熱は自然保護、温泉との共存を考える必要がある。例えば PV では、北海道厚岸が新たに国定公園に指定されたが、周辺の牧草地が PV パネルで埋められるという問題が起きている。
- 今後 10 年が将来を決する期間と言われている。新たな技術も必要だが、現有技術をいかに最大限に活用していくかを議論する必要がある。
- 環境問題だけでは国民理解が得られないのではないか。新たな豊かさを生み出すもの、という視点が必要。分散型、地域循環型の社会を構築することが重要と考える。コロナ禍を新たなライフスタイルへの転換、新たな豊かさの創出の契機とすることが必要。
- 分散型の地域づくりではドイツが先行しており、学びたい。

質疑

- 日本は 2050 年に水素やアンモニア 10%とあるが、アンモニアの中間目標はどのようなものか。
  - ➢ 2030 年までにコストを削減し、その後普及を加速する。用途は石炭火力での混焼を想定している。供給側では中東諸国からの輸入計画を進めているところである。次の段階では普及を促すインセンティブが必要と理解している。
- 日本の炭素価格はどのような状況か。
  - ➢ 炭素価格については環境省と経済産業省各々で議論し、報告書を出している。現時点では明示的な炭素価格はない。炭素価格の導入も議論されるかもしれない。日本は元々エネルギー価格が高いことから、追加コストの負担に反対が強い。
- EU からは Fit for 55 に応じたインフラを扱うパッケージが出てくる予定である。電力やガス・水素のネットワークを見直す必要がある。欧州の産業を守るために ETS の無償割当を行っているが、これを無くしていかなければならない。新技術を支援する必要もある。両者を実現するための新たな政策を構築する必要がある。
- CBAM がどのように機能するのかについて非常に興味がある。現行案では鉄鋼やセメントなど特定の産業を対象としているが、今後対策が進むにつれて影響は全産業に及ぶハズ。

**The GJETC's study program 2021**

Study 1: Decarbonizing energy intensive industry

- 電力料金や税の減免措置など、日本とドイツの鉄鋼業のコスト環境の違いに関心がある。

Study 2: Long-term scenario analyses up to 2050

- 戦略の裏にある作成プロセスに関心がある。
- 日独とも出力の変動する再生可能エネルギーのシェアは増えるだろうが、クリティカルミネラルの集中をどう見るかに関心がある。
- 従来は石油がセキュリティの中心であったが、セキュリティの重心がシフトしていると理解。
- 1）日独の大きな違いの一つは送電連系有無であるが、これがどのように貢献しているのか、2）省エネを具体的にどう進めるのか、3）シナリオの結果としてコストやマクロ経済へのインパクトをどう捉えているか、に関心がある。
  - ➢ ドイツ産業連盟（BDI）で 2030 年の設備投資について分析を行っている。コストを下げることを考える必要がある。
  - ➢ 統合コストがどのように扱われているのかは重要。ドイツではコストが下がると評価している。
  - ➢ VRE の系統統合コストよりも水素や建物への投資の方が大きいと見ている。また

移行期のコストを検討する必要がある。

- 例えば、人々大きな部屋に住みたいという希望がある一方、気候変動の観点からは住まいはコンパクトにすべき（個人のニーズと気候目標は相反）。交通の在り方も重要。
- 第 1 に現存技術でどこまでできるのか見極め、第 2 に新技術の可能性を探り、最後に思い通りにならない現実社会を方向付けるための政策を考えるのだと考える。ロードマップがあれば民間は巨額投資を行うことができる。
- 電力コストは 2030 年にかけて上昇するもののその後低下すると見ている。ドイツの周辺国との電力融通は多くなく、それだけがコスト低下を見込む要因ではない。
- 欧州はガスパイプランが発達しているため、純水素を輸送することができ、コスト面で優位。日本はそうでないため、アンモニア等キャリアに転換する必要がある。
- 社会の受容性の問題は日独共通。
- 野心的なシナリオを実践するために必要な措置、行動が重要。

Study 3: Distributed energy systems and the role of batteries

- リサイクル可能な量に興味がある。
- 電池のサプライチェーンで見る必要がある。リサイクルを前提とすれば、原料を生産する鉱山への投資はそれほど必要ないかもしれない。チェーンの各段階でいかに投資を確保するかが課題。

**Selected policy tools for climate neutrality: German/EU initiatives and draft outline of the GJETC topical paper**

- ドイツでは建物や交通分野にも炭素価格を課すことを検討している。
- 炭素価格について日本でも様々な議論がされており、日独の比較ができると興味深い。日本では明示的な炭素価格（炭素税、排出権取引）だけでなく非化石証書など暗示的な炭素価格もある。
- 京都議定書では CDM など国際メカニズムがあったが、パリ協定では制度化されていない。国際的な排出権が活発になれば日本が目指す水素やアンモニアの貿易が不要となるかもしれない。
- CBAM が目指す国際競争の条件を揃えるという視点では、国際比較の正しい物差しが必要。
- 京都議定書の時は、日本はウクライナから多額を投じて排出枠を購入した。現在のパリ協定では CDM の後継や JCM が議論されているが、京都議定書の時とは違い途上国自身も削減目標を掲げているため、出てくる排出権の量はそれほど大きくないのではないか。また、パリ協定には罰則がないことも、排出権の国際取引にとってネガティブな要素。

Suggestions for Innovation Partnerships and Innovation Roundtable

- 産業の廃熱利用の潜在性は巨大。ドイツの CO2 排出の 40%が建物とその建築プロセスからであり、ヒートポンプの活用可能性は大きい。冷熱や建物の断熱性能も重要である。
- 廃熱利用は省エネなので、産業によっては秘匿情報にあたるかもしれない。それよりも、鉄鋼やセメントなど化石燃料を使わざるを得ないプロセスの脱炭素化技術に焦点を当てた方が良いのではないか。
- 産業廃熱の利用ポテンシャルは大きいが、2050 年/2045 年に CN を達成した時点では、産業は CN な電気や水素を使っている。そのため CO2 削減という意味での省エネは無用となっている。省エネは産業の競争力という別の視点で必要になるのではないか。
- BEV 以外の脱炭素自動車の動向も検討に値する重要な分野ではないか。FCEV や e-fuel はどうか。日独で補完できるのではないか。
- ドイツでは合成燃料を、BEV を補う候補とみている。どのような時間軸と価格で利用可能となるかがカギ。BEV の市場見通しを狂わすことになるため、自動車メーカーは貨物車に e-fuel を導入することに反対している。
- 交通セクターは技術だけでは対策出来ない領域。1.5℃目標の達成に向けて対策を進めると同時に、自動車産業をどうするのか、ということも関係する。

日独エネルギー変革評議会（その２）
2022 年 2 月 24 日、25 日

Change of government in Japan and Germany: consequences for climate mitigation action and the GJETC

ドイツ

- ドイツでは選挙によって連立政権が成立。省庁の再編が進行中であり、今後は各種規制の見直しも行われる可能性がある。新政権のもと、2022 年 4 月に最初の政策パッケージが、夏に第 2 弾、2023 年に第 3 弾が出てくる。EU レベルでも、Fit-for-55 パッケージと 2021 年 12 月パッケージ、補助金に関するガイドライン見直し（補助金削減）案が出された。
- 連立政権の合意によると、2030 年までに 65%減、2045 年までに CN という目標を再確認。2030 年に再エネ 80%、2030 年に熱供給の半分を再エネに、石炭火力は 2030 年までに全廃、水電解能力を 2030 年までに 10GW、2030 年までに BEV を 1500 万台、といった目標が示された。
- EU の制度が日々変化。ドイツ国内では、今後不要となるエネルギーインフラの廃止に対する注目が高まりつつある。
- ドイツの水素供給は輸入も想定している。2030 年時点で需要の 50%しか国内で生産できない見込みである。輸入に際しては、認証制度の整備も重要。水素輸入地域の限定、グリーン水素であること、パイプラインの有無、輸出国のガバナンスが重要。
- ドイツが提唱する「気候クラブ」は定義がまだ曖昧。加盟国間で炭素価格を揃える必要があるが、短期では困難ではないか。

日本

- 日本でも政権交代が起こったが、同じ自民党政権でありドイツほどの大きな変化はない。
- 従来の目標は 2030 年に 26%減、その後 2050 年 CN に向けて削減が加速する想定であった。菅政権が出した 2030 年 46%削減目標は、従来と異なり 2050 年 CN からのバックキャストで定めたもので、性格が異なる。
- 2050 年を視野に入れた 2021 年 6 月のグリーン成長戦略では、今後成長が見込まれる分野、優先的に開発する分野を示している。
- 2030 年 46%削減に向けて、（第 6 次エネルギー基本計画では）電力需要見通しの引き下げと、再エネ比率の引き上げが行われた。
- 岸田政権の施政方針では、長期的な社会や経済の変化も含むクリーンエネルギー戦略の策定を示している。アジア地域の脱炭素への協力も明記しており、今後方向性が出される見込み。

- 日本の電力消費が 2030 年にかけて減少する見通しとなっているのは、省エネ効果が電力化による需要増を上回るため。
- 日本では、政府は水素戦略を定め、予算措置を講じ、規制緩和も行っている。

**The GJETC's study program 2021/22**

Study 1: Decarbonizing energy intensive industry

- ドイツでは BECCS が有効とあったが、想定するバイオマスは何か？2030 年時点で直接還元法は現実的か？2050 年に CCS が安くなるメカニズムは？
  - 2030 年の直接還元は天然ガスを使ったものであることから安価。2050 年は技術の成熟による CCS コスト低下を想定。
  - 天然ガスを利用した直接還元は既に一部行われている。CCS は外部コストの小さいことが有利。
- 日本側政策提言には「国際競争力の維持」という視点がないが？
  - 気候クラブのようなものが産業保護対策になると考えられる一方、そうした制度が自由貿易を阻害する可能性もあり、妙案がない。
- 鉄鋼の脱炭素は現実のものとなりつつある。ドイツでは直接還元法による脱炭素に資金援助を行うことが決まっている。日本ではどのような投資が計画されているか？
  - グリーンイノベーション基金で支援が行われる。COURSE50 が継続するほか、CCUS でメタンを合成し船舶燃料にする計画が進んでいる。日本は天然ガスが高価であることからそれを利用した直接還元は視野に入っていない。
- 資源循環による脱炭素という議論はないのか？
  - 電炉へのシフトが該当。一方電炉法ではスクラップの安定供給が課題となる。

Study 2: Long-term scenario analyses up to 2050

- ドイツのシナリオの課題には、省エネの深掘り、循環経済の効果の反映、マクロ経済効果の分析、リバウンド効果など十分性（sufficiency）の考慮、などがある。
- 日本のシナリオの課題には、社会的受容性への配慮、CCS のポテンシャル、輸入水素・アンモニアのリスク、などがある。

Long-term perspectives of the BDI "Climate Paths 2.0"

- BDI（ドイツ産業連盟）は Climate Paths 2.0 を策定。今回は投資の視点から政策提言を導出。
- ゼロカーボンエネルギーインフラへのアクセスを拡大すること、エネルギー価格が上昇するなかで競争力を維持することが課題。
- 対策の中心は電力化であり、その結果需要が増加。電力供給では、再エネのみならずガス火力も必要と分析。また、水素や合成液体燃料（輸入）も必要となる。自動車用には

充電インフラ、貨物車用の水素ステーションが必要。

- これらのシナリオに必要な投資は計 EUR8,600 億と試算。2025 年から 2030 年にかけての財政負担は排出権取引や炭素税による歳入を大幅に上回ると試算。
- 再エネが増えるなかクリティカルミネラルのセキュリティいう視点も必要ではないか。エネルギー価格の上昇は産業界にとって大きな課題と思慮。CBAM は一部の産業しかカバーしていないが、対象の拡大を期待しているのか？その実現可能性をどうみているか？
  - エネルギー価格は当初上昇するが、その後低下していくと見ている。水素についても世界で普及が進めばコストも低下すると期待。CBAM を特定の分野で試してみることがよいのではないか。気候クラブも「締め出し」ではなく、変化の後押しとなることを期待。
- 日本は 3R が進んでおり、それを発展できるのではないか。社会を巻き込み、誰も取り残さないことが重要。ライフスタイルの変更を可能とする枠組みが重要。
- 社会的受容性は重要であり、多くの分析で過小評価されている。また、デザーテック（サハラ砂漠の太陽光発電の電力を欧州に送電する計画）や昨今のガス価格問題など、従来のシナリオには地政学的な考慮が欠けていた。貯蔵能力や革新的な素材開発の効果をどう見ているか。
  - ドイツの分析例では、貯蔵や素材の評価は一部調査でされているが不十分。
  - 日本の分析例では、再エネ 100%の場合非現実的な規模の蓄電池が必要との分析結果がある。
  - ロシア-ウクライナ問題は天然ガス利用戦略に大きな見直しを求めている。シナリオを再考する必要があるかもしれない。
  - 化石エネルギーへの依存を減らすことが求められ、再エネに加えて原子力の利用や石炭のアンモニア混焼、天然ガスの供給力・多様性・柔軟性の向上が重要。

Study 3: The role of batteries towards carbon neutrality

- 蓄電池の安全性に関する評価はどうか？
  - 安全性はリサイクルのなかで需要な評価項目。
- 他の分野におけるリサイクルの経験から何か学べることはあるのか？
  - リチウムイオン電池は大量の危険物をリサイクルする必要から、輸送、処理事業者の認定や製造事業者に対する義務など、定めるべきことは多くある。
- ドイツでは蓄電池の回収が論点となっている。中古自動車が輸出されるようなケースでは、販売者などに管理義務を課すなどする必要。
  - 日本にも類似の問題がある。日産リーフの場合、日産が回収するよりも多くの中古車が輸出されていることが分かっている。
- BEV を利用した需給調整効果を分析中。分析では 2030 年時点の VRE の出力制御を 3

割削減できるとの結果。

- ドイツでは家庭用に蓄電池を設置する例があるが、現在は経済性がない。PHEV も補助金の対象になっているが、補助の対象は BEV のみとすべきではないかとの議論がある。日本はどうか？
  - ➢ 再エネ普及率は欧州の方が高い。自動車の LCA での GHG 排出量は電力ミックスによる。電源のクリーン化の速度に合わせて自動車のクリーン化を進めている。家庭用蓄電池については、PV を設置している家庭に重点的に設置していく計画がある。
  - ➢ PHEV については、ユーザーの選択もある。ユーザーに選択される技術であることが重要。
- 蓄電は逆に系統に負荷をかけることもあり、スマートチャージングが必要。電力供給の自立という点では、家庭単位でなく地域単位で行うことも考えられる。
- COP26 において、イギリスが内燃機関自動車販売禁止のタイムラインを示したが、自動車産業を持つ国は参加しなかった。国家が産業を規制する手法をどう評価するか？
  - ➢ 運輸部門の GHG 排出を減らすために e-mobility に置き換えることが必要であり、EU の規制はその方向に進むであろうと思慮。

Energy and carbon prices and the reduction of fossil fuel subsidies

- ドイツでは、EU-ETS の価格上昇によって政府は多くの収入を得、気候変動基金に組み入れることができた。化石エネルギーには炭素税を課しており、この収入も気候変動基金の原資となる。この他にもエネルギー税があるが、このうち Ecotax は税収が年金保険の原資となっていることへの批判がある。また、免税措置が多くあることへの批判もある。
- 日本では、様々な種類の明示的、暗示的な炭素税がある。各種税や FIT の負担を加えると、小さくない負担がかかっている。このほかにも、自治体による ETS もある。日本とドイツのエネルギー価格は既に国際的に高い水準にあり、今後もその影響を踏まえた施策が必要。
- ドイツでは CBAM などの議論が、日本では「成長に資する炭素価格」という視点で議論が進行中。
- 欧州での CBAM の議論は日本に影響しているのか？
  - ➢ CBAM の動向は注視している。
- ①EU-ETS は 2005 年の開始から 20 年経過したが、もっと短期で導入できた可能性は②ETS と税をどう使い分けるのがよいか？③従来の税収は道路建設などを目的としたものもあるがこれは維持されるのか？
  - ➢ ①について、外部からの市場への介入が影響し、またオークション制度の構築に時間を要した。現在は価格の管理に成功。②について、ETS 以外の分野で税を利用。

排出者と負担者の関係をどう定義するかによる。

Report on Innovation Roundtable results and follow-up activities

- 机上で議論するのみならず、GJETC から実業の利益が生まれるのはよいこと。
- 意欲的なアプローチで評価したい。GJETC 自身は学術的な組織であることから、橋渡し役に徹することが重要。

Extending the cooperation of the GJETC beyond March 2022

- 2050 年前に CN 達成を目指す中では、イノベーションを待てないのではないか。イノベーションを要しない手法にも着目すべきではないか。産業のなかでは、製鉄の脱炭素は極めて難しく、中国の鉄鋼業を利するだけになるかもしれない。鉄鋼の脱炭素の限界を見極めることが重要ではないか。
- 議論の継続を期待。CBAM や気候クラブは今後 2-3 年政策的議論が高まると考えられる。
- コロナ禍の 2 年間で新たな社会科学上のデータが得られた。自然実験の結果をエネルギー分野に応用できるのではないか。
- ガス火力の水素転換は欧州では比較的詳細な分析がすでにあり、追加的な分析の可能性、必要性を確認する必要がある。逆にアンモニアはドイツでは議論になっておらず、新規性があるかもしれない。CBAM は大きな議論になるが、カーボンリーケージを防ぐための政策ミックスと幅を広げて考える方が良い。CN のためにインフラ（新設、既存インフラの拡張・撤去）の分析を行ってはどうか。ドイツの鉄鋼業は脱炭素に向けて動いている。コロナの影響については、長期的な影響の有無という点で良く分からない。
- 既築の脱炭素は良いテーマ。建物を建築する際の CO2 排出が議論となっている。鉄やセメントなどの素材、運搬の過程でも CO2 を排出する。これらを扱ってはどうか。
- CCS についてドイツで政策を準備中であり、学びあうことができるのではないか。LNG など既存技術の状況の日独比較も興味深いのではないか。
- 既築の脱炭素は良いテーマと思慮。日独で異なるアプローチがあるため、比較分析に意義がある。ドイツでは建物のライフサイクルでの GHG 排出評価に関心が高まっている。イノベーションのみならず即効性のある既存技術にも目を向けるべきとの指摘に賛成。
- 多くの議論は分野を絞ったもので、複眼的な視点が不足しているのではないか。その意味で社会学的なテーマを取り上げても良いのではないか。都市の脱炭素ということを考えると、社会の意思が非常に重要になる。
- 水素については、高価格な水素の導入支援策に関心。燃料アンモニアについては日本からドイツに情報を与えることができるのではないか。

# 付録２．エネルギー多消費産業の脱炭素化 – 鉄鋼産業 –

# Steel Sector Decarbonization

Authors: Thomas Adisorn; Yoshikazu Kobayashi

March 2022

# Content

# Figures

Figure 18 $CO_2$ emissions from the Japanese steel industry ............................................ 34


# Tables

# 1 Introduction

Germany and Japan both have a strong steel industry, contributing to both economic well-being as well as greenhouse gas emissions. If steel is to be made in both countries in the future while avoiding carbon leakage, which is the relocation of industries to countries with laxer environmental standards, the Governments of Japan and Germany will need to actively support the sector's transformation.

For both countries, we describe the steel sector and roadmaps that have been outlined towards climate-neutrality by 2045 in Germany and by 2050 in Japan. We also pay attention to policy developments and options. While we found many similiarities between both countries, we also identify differences, including technology perceptions, e.g., regarding the "colours" of hydrogen or carbon capture and storage. We conclude with policy recommendations addressing the individual governments.

# 2 Germany

## 2.1 Industry overview

### 2.1.1 Major firms and revenues

In Germany, 4 million people are employed in steel-intensive businesses and steel industry directly employs 87.000 people. Revenues of the industry have recovered since the financial crisis in 2009. From 33.1 bn in 2009, total revenues climaxed at 49.7 bn in 2011. Then, revenues decreased until they reached 35 bn in 2016, which was followed by better figures in 2017 and 2018. Latest available data show that total industry revenues were at 39.1 bn in 2019 (WV Stahl, 2021).

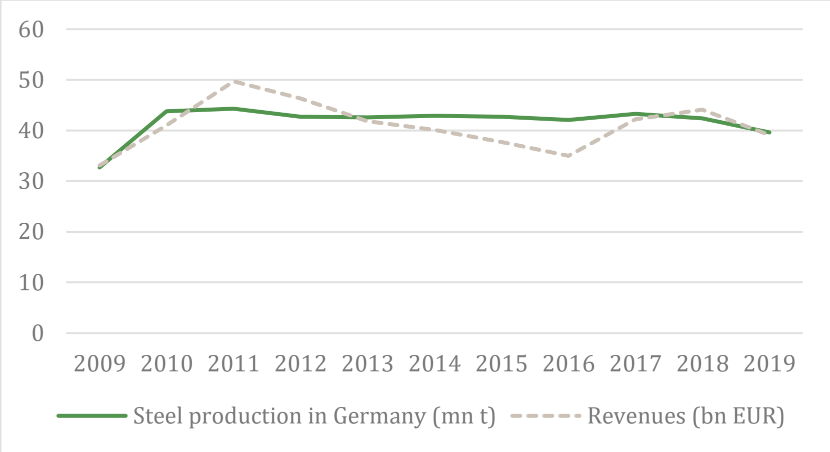



*Figure 1: Steel production and revenues in the German steel industry between 2009 and 2019 (own figure based on WV Stahl, 2021)*

In the last ten years, steel exports have been between 24.8 and 27.3 mn tons, whereas imports have been between 24.4 and 28.5 mn tons. In this period, Germany always imported slightly more, but in 2019 the trade balance almost neutral. Available data for the European steel industry shows that, in 2020, the top-three importers of European steel are Turkey (24 %), the United States (10.8 %) and China (7 %) for flat steel and Switzerland (13.2 %), Canada (9.3 %) and Turkey (9.2 %) for long products (statista, 2022).

Key demand sectors of the steel industry are construction and automobiles, followed by metals, machinery and pipes (WV Stahl, 2021).

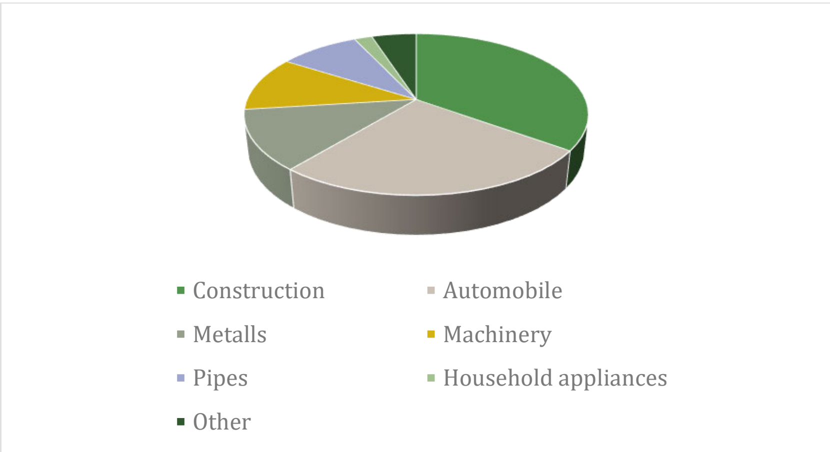



*Figure 2: Demand side sectors of the steel industry in Germany (own figure based on WV Stahl, 2021)*

The following figure provides an overview of steel production sites in Germany.

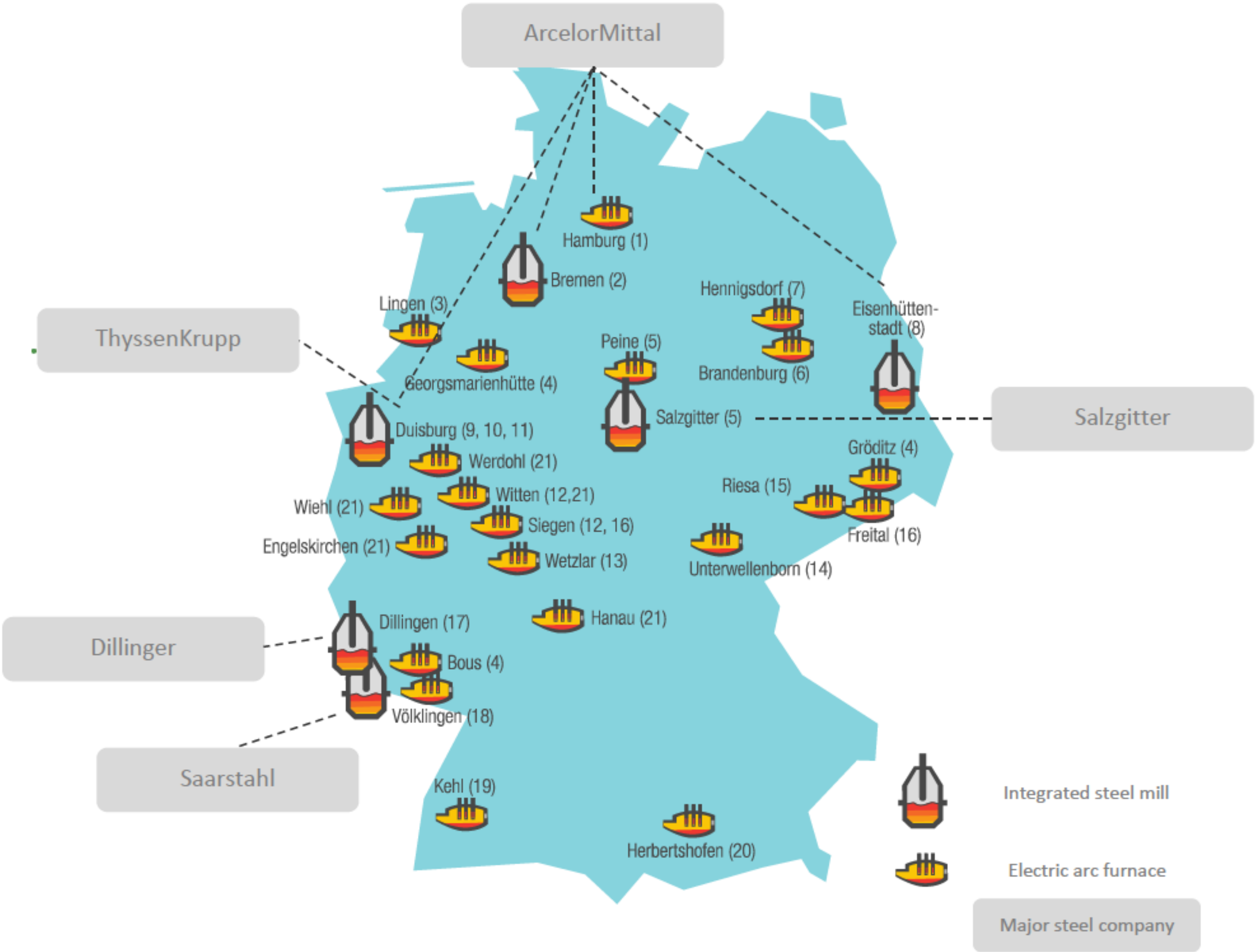



*Figure 3: Steel production sites in Germany (WV Stahl 2020 with minor adjustments)*

The country's largest steel producer, ThyssenKrupp, has its production facility in Western Germany and is capable to produce 12 mn tons of crude steel annually. Like ThyssenKrupp, ArcelorMittal has a steel plant in Duisburg, but further plants are located in Northern and Eastern Germany, allowing for a total production capacity of 9 mn tons of crude steel per year. The company Salzgitter produces in Central Germany, and annual production amounts to 6.6 mn tons of crude steel. The steel plant of Krupp Mannesmann also located in the city of Duisburg has an output of 5.6 tons of crude steel per annum. The companies Dillinger and Saarstahl, both headquartered in Germany's Southwest, have annual production capacity of 2.8 mn and 2.7 mn respectively. All of those companies produce primary steel through the blast furnace-basic oxygen furnace. Apart from these companies, several steel producers in Germany only produce secondary steel via electric arc furnaces (WV Stahl, 2021).

*Text box 1: Today's dominant production routes*

The dominant method of making primary steel is the route via the **blast furnace-basic oxygen furnace** (BF-BOF). These are two integrated processes where the blast furnace is needed for ironmaking, whereas the basic oxygen furnace converts hot metal into steel (Kempken et al., 2021). In this process, carbon is necessary as a reducing agent, for which coke is traditionally used. **Electric arc furnaces** (EAF) are for recycling scrap and turning it into (secondary) steel. Graphite electrodes are necessary for the melting process. 30% and 40% of all steel production is from the secondary route in Germany and the EU, respectively (EUROFER, 2020; WV Stahl, 2021)

### 2.1.2 Historical background

Before Friedrich Krupp founded his steel plant at the beginning of the 19th century, steel was imported mostly from England. August Thyssen became a competitor in 1870. After World War I and II, Germany's steel industry became a symbol of economic recovery, but the financial crisis of 1973 hit the industry hard, and global competition increased in the years to come (Maier-Bode, 2018). In 1961, employment in the steel industry reached its climax with 421.000 people working in the sector. After the crisis, in 1978, only 300.000 were employed in the steel industry (Maier-Bode, 2018; Schlucht, 1998; WV Stahl, 2021).

Steel plants were originally built up in locations with available energy resources, that is coal. Moreover, locational advantages also included opportunities to further process steel and to ship resources (iron ore) and final products. Both, iron ore and coal extracted domestically in Germany became uncompetitive, which is why the role of ports has turned into a highly relevant locational factor for steel production; sites without access to waterways closed down successively in Germany (Schlucht, 1998). Today, regional clusters between steel / metal industry and downstream industries as well as research institutes exist, which is considered to be an important advantage (IfW Kiel & McKinsey & Company, 2020).

### 2.1.3 Types of processes used

In Germany, the primary BF-BOF-route is the dominant route of steel production (see text box 1). Around 70% of steel is produced via this route with an average energy demand of 14 GJ per ton of steel and emissions of 1.7 ton $CO_2$ per ton of steel. The secondary route is responsible for most of the rest, with far lower energy- and $CO_2$ -intensity per ton steel. A tiny share is produced by making use of direct reduction using (at the moment) natural gas (see text box 2). In the end, the primary route using coke as a reducing agent is responsible for the lion's share of $CO_2$-emissions (Agora Energiewende & Wuppertal Institut, 2019).

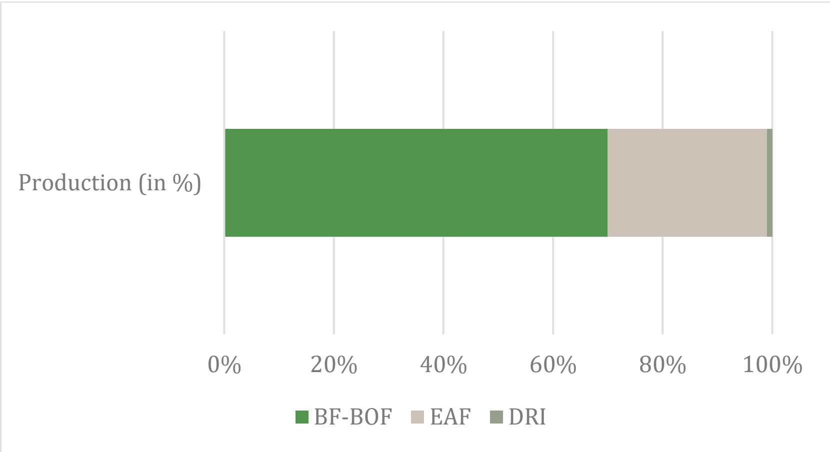



*Figure 4: Steel production route in Germany (own figure based on Agora Energiewende & Wuppertal Institut 2019)*

*Text box 2: Direct-reduction technology*

In order to reduce iron ore, the BF-BOF route makes use of coke, while direct reduction plants can work with hydrogen as a reducing agent and, in so doing, produce sponge iron or **direct reduced iron** (DRI). Hydrogen-based direct reduction does not produce process-related $CO_2$. The DRI needs to be further processed in an **electric arc furnace** (together with scrap if required) to, basically, produce crude steel. Natural gas or even a blend of hydrogen and natural gas can also be used in DR plants. Green hydrogen for direct reduction as well as renewable electricity for the EAF have the potential to realize substantial $CO_2$ reduction (Agora Energiewende & Wuppertal Institut, 2019).

### 2.1.4 Other relevant factors affecting decarbonization of the steel industry and effects of the past decarbonization policies

Substantial emission reductions were achieved in the 1960s, when former processes (Siemens-Martin- and Thomas-Stahl) were substituted through oxygen- and electric steel due to better economic performance. In 1964, a first a relevant law ("Technische Anleitung Luft", Engl.: Technical Instructions Air) was introduced with minimum performance values to limit air pollution concentrations regarding sulfur dioxide and nitrogen concentration. Since 1974, the Federal Immission Control Act has successively and successfully introduced tighter performance values and, for instance, resulted in investments in cleaning units and reduced use of fossil fuels. This is considered to be responsible for $CO_2$ -reductions. While in the first half of the 1970s, environmental regulation was stricter in competing countries such as Japan and the U.S., regulations formulated from 1975 onwards resulted in cost increases, according to the industry. In parallel, new players (also from emerging economies) entered the global steel market (Ketelaer & Vögele, 2014).

In 1999, Germany introduced a ecologic tax reform, which was supposed to act as a steering instrument. However, resistance from energy intensive industries resulted in tax breaks and, thus, low pressure to change investment behaviour towards environment-friendly technologies. Moreover, in 2000, economic actors agreed to voluntarily reduce $CO_2$-emissions until 2012 by 28 % compared to 1990, which included a 22% reduction target per ton of crude steel. The government promised to waive regulatory initiatives such as obligatory energy audits. While the 22% reduction target was achieved, it is assumed that this is largely due to the expansion of the EAF-route having taken production shares from the BF-route (Fleiter et al., 2013).

In 2013, the Industrial Emission Directive of the EU became effective, which requires steel producers to invest in best available technologies. Since 2008, the European steel sector has participated in the Emission Trading System of the European Union (ETS). Between 2008 and 2012, certificates had to be bought for 3% of total emissions; between 2013 and 2019, this share was increased to 28% of total emissions of the steel sector. Generally, the allowance price has been at low levels for several years that were insufficient for motivating steel producers to carry out costly investments (Kempken et al., 2021; Ketelaer & Vögele, 2014).

An important factor in designing instruments for energy intensive industries including steel is their exposure to global trade and competitors. Costs incurred by regulation is feared to reduce competitiveness and may result in ‘carbon leakage’: the dislocation of steel companies to countries with less strict (and, thus, less costly) environmental regulation. Little empirical evidence has be identified for carbon leakage so far, also because of low $CO_2$-prices and free allowances (Kempken et al., 2021).

## 2.2 Decarbonization roadmap

### 2.2.1 Mid- and long-term emissions reduction goals

Steel industry is responsible for 29% of all industry emissions in Germany. It is the largest $CO_2$ -emitting industry sector followed by basic chemicals (19%). In 2021, Germany’s Climate Protection Law was revised. Compared to the base year, which is 1990, Germany committed to reduce total emissions down to 35% in 2030 and 12% in 2040. Climate neutrality must be achieved by 2045. For the industry sector, the government strives to achieve 42% of base year emissions in 2030, i.e., a reduction of 58%. This is weaker compared to Germany's overall emission reduction targets of that year. For 2040, the government did not set an intermediary target for industry so far. Moreover, industry targets have not been broken down for individual industry sectors, meaning that there is no obligatory steel stector emission reduction target.

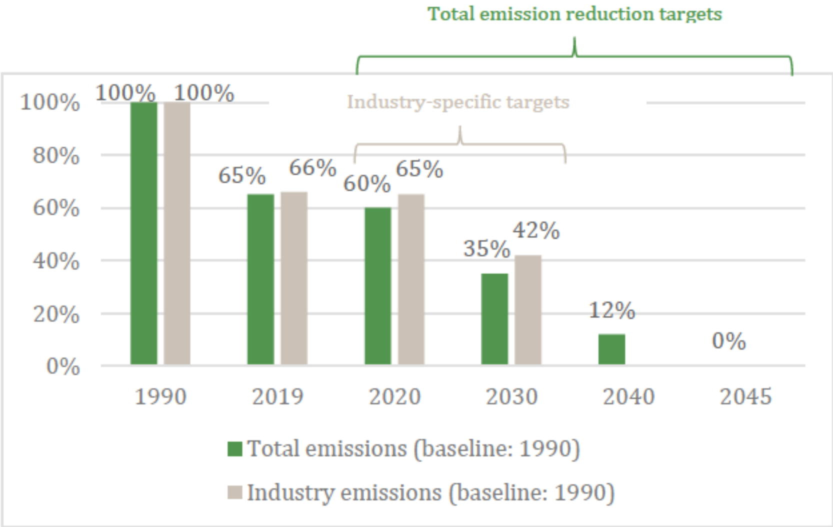



*Figure 5: Policy objectives based on the revision of Germany's Climate Protection Law*

Germany's largest steel producers are committed to achieve climate neutrality by the middle of this century. ThyssenKrupp and Salzgitter have pledged to contribute to Germany revised climate objectives by 2045. By 2030, ThyssenKrupp plans to reduce emissions by 30% compared to 2018 levels and to become climate neutral by 2045 (Thyssenkrupp Steel, 2021). Salzgitter recently announced ambitious plans to reduce emissions by 50% by 2030 and 95% by 2045 compared to 2018 levels (Rehrmann & Plettendorf, 2021; Salzgitter AG, 2022). The other large players, including ArcelorMittal as well as Dillinger and Saarstahl, strive for climate neutrality in 2050 but might align their company targets in accordance with the government. ArcelorMittel is committed to reduce emissions of its European steel plants by 30% by 2030 before becoming climate neutral in 2050.

### 2.2.2 Elaboration of emissions reduction path

In the literature, several scenarios were modelled showing possible pathways for climate neutrality in the steel sector until the middle of this century. The following figure mirrors analyses aligned with the latest revision of Germany's Climate Protection Law.

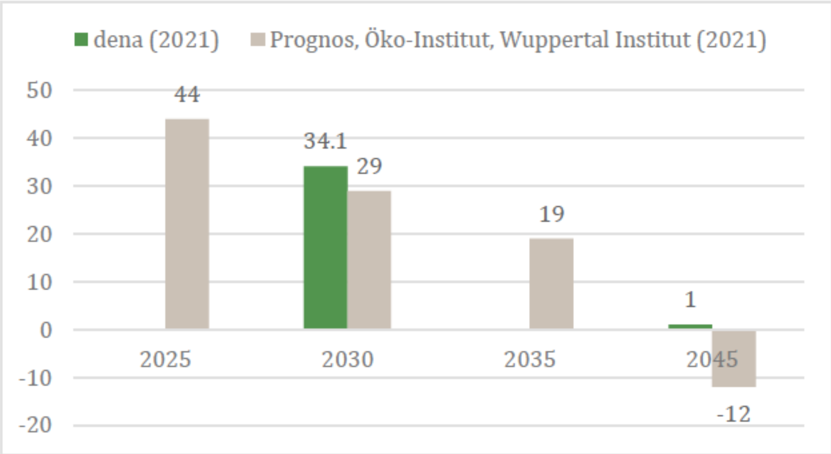



*Figure 6: Modelled steel sector emission reduction pathways (in million t $CO_2$-eq, own figure based on dena, 2021 and Prognos, Öko-Institut, Wuppertal Institut, 2021)*

Data provided by Prognos, Öko-Institut & Wuppertal Institut is a bit more detailed with more intermediate steps. In contrast to dena (2021), authors assume that steel industry will become a carbon sink from 2040 onwards. This is achieved by assuming that almost all sustainable biomass available in Germany will be used in industry and coupled with CCS (BECCS) (for a brief explanation, see text box 5, p. 14 in this report), whereas other scenario studies still assume the use of biomass in buildings or transport.

### 2.2.3 Assumed decarbonization actions

The following figure shows the production routes in 2030 and 2045 based on the two scenarios mentioned above as well as on another scenario from the Federal Association of the German Industrie (BDI 2021).

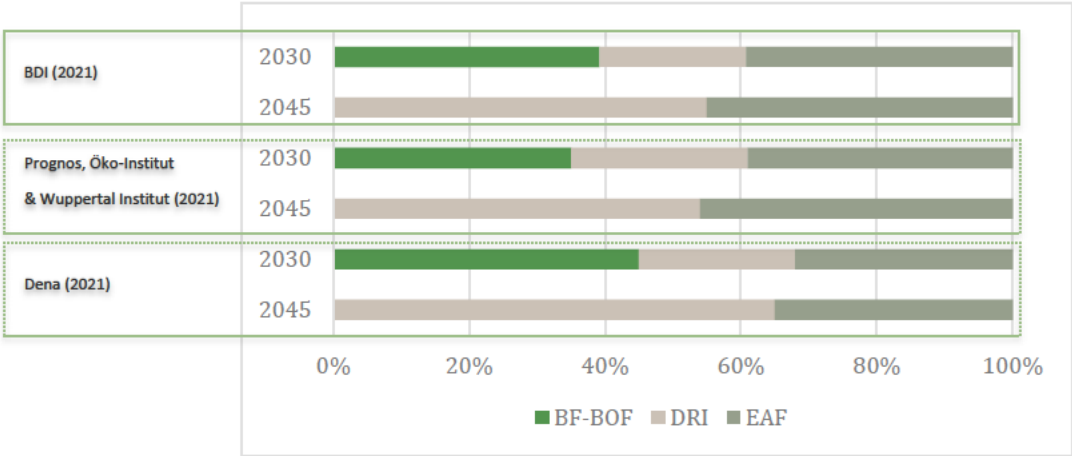



*Figure 7: Distribution of production routes modelled for 2030 and 2045 in dena (2021) and Prognos, Öko-Institut and Wuppertal Institut (2021) (own figure)*

BDI (2021) assumes that both, primary steel from the BF-route and secondary steel, will individually account for 40% of total steel production in Germany by 2030. Between 2030 and 2045, BF-steel will be phased out completely, and direct reduction will be the dominant method to produce steel with EAF-steel will only gain negligible shares.

Prognos, Öko-Institut and Wuppertal Institut (2021) assume that BF-based production will decrease substantially from 70% in 2019 down to 35% in 2030, while DRI- and EAF-steel will increase to 26% and 39%, respectively. Hence, for 2030, the secondary route will be the dominant pathway to produce steel. In the middle of the century, BF-production will be phased out completely, while DRI- and EAF will be more or less on equal footing as regards shares in steel output. In this scenario, decisive steps towards steel sector decarbonisation are that new BF will not be commissioned any more, but all necessary reinvestments are made in DR-plants, which are modeled to make use of only 20% natural gas and 80% hydrogen as a reducing agent.

The scenario by dena (2021) is a bit more conservative as regards the expansion of steel production through DRI-technology and EAF in 2030. Less than a quarter of steel will be produced via direct reduction relevant for 10 mn tons of carbon-free steel, almost half of steel will still come from the conventional primary route. However, in the middle of the century, DRI-technology will produce two thirds of steel production (and 30 mn tons of carbon-free steel), while the rest will be from the secondary route.

Both scenarios expect hydrogen to play a substantial role in steel sector decarbonisation. In 2030, both scenarios assume hydrogen use between 15 and 26 TWh, which is 24% and 40% of total hydrogen demand in Germany modelled. For 2045, hydrogen use in steel production will amount to 35 and 75 TWh, equivalent to 13% and 17% of Germany’s total demand for hydrogen (Deutsche Energie-Agentur, 2021a; Prognos et al., 2021). As regards the EAF-route, Prognos, Öko-Institut and Wuppertal Institut (2021) are more optimistic about it. Especially in the long run, authors expect a bigger role of recycled steel. Due to the dominance of primary steel from DR-plant in dena (2021), the demand for hydrogen is assumed to be higher. Moreover, the use of biogenic syngas reduces the need for hydrogen in Prognos et al. (2021) relative to dena (2021).

As provided in the following table, analysis suggests that direct reduction technology can bring about substantial emission reductions. This includes the more immediate time frame until 2030, for which authors assume a blending of natural gas with 7.5% hydrogen, as well as the long run until 2050. CCS may achieve similar results until 2050, but – as will be shown later – questions regarding safety at storage sites will be an issue. CCU may not achieve the emission reductions necessary, and iron electrolysis has a relatively low technology readiness level (TRL).

*Table 1: Emission reduction potential of selected decarbonization technologies in the steel sector (based on Agora Energiewende & Wuppertal Institut 2019)*

| Technology | Emission reduction / remaining emissions intensity | Emission reduction potential (2030) | Emission reduction potential (2050) | TRL |
|---|---|---|---|---|
| **Direct reduction** | -97% / 0.05 t $CO_2$ / t CS | 14 mn. t CO / a | 50 mn. t $CO_2$ / a | 4-5 |
| **CCU** | -50% / 0.85 t $CO_2$ / t CS | 2-6 mn. t CO / a | n. a. | 4-5 |
| **HIsarna / CCS** | -86% / 0.24 t $CO_2$ / t CS | 0 mn. t CO / a | 44 mn. t $CO_2$ / a | 4-5 |
| **Iron electrolysis** | -87% / 0.22 t $CO_2$ / t CS | 0 mn. t CO / a | < 1 mn. t $CO_2$ / a | 1-3 |

*Text box 3: Other decarbonization technologies*

**Carbon capture and utilization** (CCU) in the steel industry allows metallurgical gases produced in the BF-route to be separated and used e.g. for the production of valuable chemical substances (e. g. methanol, ethanol, synthetic fuels, ammonia). Used this way, metallurgical gas must not be burned in on-site power plants anymore. However, green methanol, for instance, requires green hydrogen as an ingredient, which is why CCU is electricity-intensive. The HIsarna process is a new type of coal-based smelting reduction process. Its advantage is a relatively pure $CO_2$ waste gas stream and, thus, it can be more easily combined with **carbon capture and storage** approaches. The removed $CO_2$ would, then, have to be transported to geological storage sites. In (alkaline) **iron electrolysis**, iron ores are reduced to pig iron and then melted to crude steel in an electric arc furnace without a carbon-containing reducing agent. The process promises a significant increase in energy efficiency compared with the blast furnace route (Agora Energiewende & Wuppertal Institut, 2019).

### 2.2.4 Menu of decarbonization technologies

Like in the aforementioned scenarios, the Federal Ministry of the Economy focuses in its Action Concept Steel on hydrogen-based steel production for producing primary steel and the electric (secondary) route (BMWi, 2020). Concepts, in which $CO_2$ emitted is either used in other processes or stored are mentioned, too.

*Text box 4: Hydrogen and its colours*

| | |
|---|---|
| Green | hydrogen produced through electrolysis powered by renewable energy |
| Yellow | hydrogen produced from electricity of the national electricity mix (often also including natural gas or coal as primary energy sources for electricity production) |
| Pink | hydrogen produced from nuclear power |
| Turquoise | hydrogen produced from natural gas making use of methane pyrolysis resulting also in solid carbon (to be used for agricultural purposes, for instance) |
| Blue | hydrogen produced from natural gas through steam reforming, where $CO_2$ emitted is captured and stored underground |
| Grey | hydrogen produced from natural gas using steam reforming technology and the resulting $CO_2$ is emitted into the atmosphere |

In designing the market ramp up for hydrogen, the German Government plans to install 10 GW of domestic electrolyser capacity by 2030 and, in parallel, to forge partnerships with other countries for hydrogen imports. While only green hydrogen from renewable electricity is considered to be sustainable in the long run, other types of hydrogen will be crucial for market creation in the short- and mid-term. Hence, for the transitional phase, Germany's National Hydrogen Strategy also highlights the importance of blue and turquoise hydrogen from natural gas (Federal Government, 2020, 2021).

There are several projects that already pave the way for this production route. For instance, Salzgitter has set up a small wind farm close to its production site in Germany and install a proton-exchange membrane electrolyser as well as high-temperature electrolyser, which can also make use of high-temperature waste heat facilitated by steel production to produce green hydrogen (Salzgitter AG, 2019). ArcelorMittal has already set up a DRI-facility but also has several other hydrogen projects in the pipeline, which include the build-up of DRI- and EAF-plants. For instance, ArcelorMittal's Hamburg plant is supposed to deliver direct reduced iron to its Duisburg plant, which will be modernised in the future; the modernisation process will include the switch from BF to EAF. ArcelorMittal also seeks to reduce energy costs by reducing heating temperature through artificial intelligence in its Duisburg plant (ArcelorMittal, 2020). The companies Dillinger and Saarstahl cooperate with the technology supplier Paul Wurth in setting up dry reforming technology. It will convert coke oven gas into a synthetic gas including hydrogen and carbon monoxide injected into the BF. The technology will reduce $CO_2$ -emissions by 12 %; by feeding in additional hydrogen, emission reduction potential may double (eisen + stahl, 2021). Several projects are supported by the government support research and development investment in technologies financially.

In the scenario developed by Prognos, Öko-Institut and Wuppertal Institut (2021), DRI-technology will also be used to make use of synthetic gases from biomass by 2040. It is one of the advantages of DRI-technology to make use of different types of gases (including natural gas / methane or hydrogen), but while combusting hydrogen only results in water, burning synthetic gases will generate $CO_2$. This biomass-based $CO_2$ needs to be captured by applying oxyfuel technology and stored at safe geological sites, if steel production is to be transformed into a net remover of $CO_2$.

*Text box 5: Oxyfuel technology and bioenergy with carbon capture and storage*

In one of the scenarios for Germany's path to climate neutrality in 2045, biomass plays an important role in the long run. Wood chips would be delivered to steel plants and converted into synthesis gas, a mixture of carbon monoxide, hydrogen and carbon dioxide, which can serve as a biogenic carbon supplier for the metallurgical processes. It can also provide heat relevant for several purposes (e. g. preheating). An oxyfuel furnace can capture bio-based $CO_2$ and pipelines are supposed to forward $CO_2$ to geological storage sites. This integrated process is also known as bioenergy carbon capture and storage (BECCS) (Prognos et al., 2021).

Another innovative project carried out by ThyssenKrupp is called Carbon2Chem, also supported by the German Government. In the project, metallurgical gases from steel production are forwarded to the chemical industry closeby, which is able to use these gases in the production process of chemical products (Thyssenkrupp Steel, 2020).

In comparison to DRI-technology, the EAF-route is state of the art already used today to recycle scrap and produce new steel. At the moment, companies offer green (recycled) steel by making use of renewable electricity. Examples include the company DEW stating that its steel integrates 100 % renewable energy and recycled scrap, resulting in only 110 kg $CO_2$ per ton crude steel (Deutsche Edelstahlwerke, 2022). The company SWT uses green electricity from Scandinavian hydropower (Stahlwerk Thüringen, 2021). The company BSW, located close to the French-German-border, seeks to feed its waste heat potential into a district heating network for communities located in Germany and France (Region Grand Est, 2020).

### 2.2.5 Economics of decarbonization

The following table showns economic figures of selected decarbonization technologies. It shows that DRI-technology offers a good compromise due to its potential to reduce emissions almost completely and at comparatively moderate abatement costs. Moreover, expected applicability in an industrial scale is possible within this decade. CCU will have high abatement costs, which is also true for iron electrolysis that is considered an option for 2050.

*Table 2: Economic figures and technology readiness levels for selected decarbonization technologies (based on Agora Energiewende & Wuppertal Institut 2019)*

| Technology | Abatement costs (2030) | Abatement costs (2050) | Additional costs (2050) | Expected applicability |
|---|---|---|---|---|
| **Direct reduction** | 60-99 EUR / t $CO_2$ | 85-144 EUR / t $CO_2$ | 36-61% | 2025-2030 |
| **CCU** | 231-439 EUR / t $CO_2$ | 178-379 EUR / t $CO_2$ | 63-119% | 2025-2030 |
| **HIsarna / CCS** | n. a. | 25-45 EUR/ t $CO_2$ | 9-16% | 2035-2040 |
| **Iron electrolysis** | n. a. | 170-292 EUR / t $CO_2$ | 65-112% | 2050 |

### 2.2.6 Major challenges to realize the roadmap

Challenges to realize steel sector decarbonization can be categorized into five central categories (see figure x). Even though these dimensions apply to both production routes, primary and secondary steel, there are noteworthy differences. The following section provides an overview of the challenges also factoring in differences regarding the decarbonization technologies discussed above.

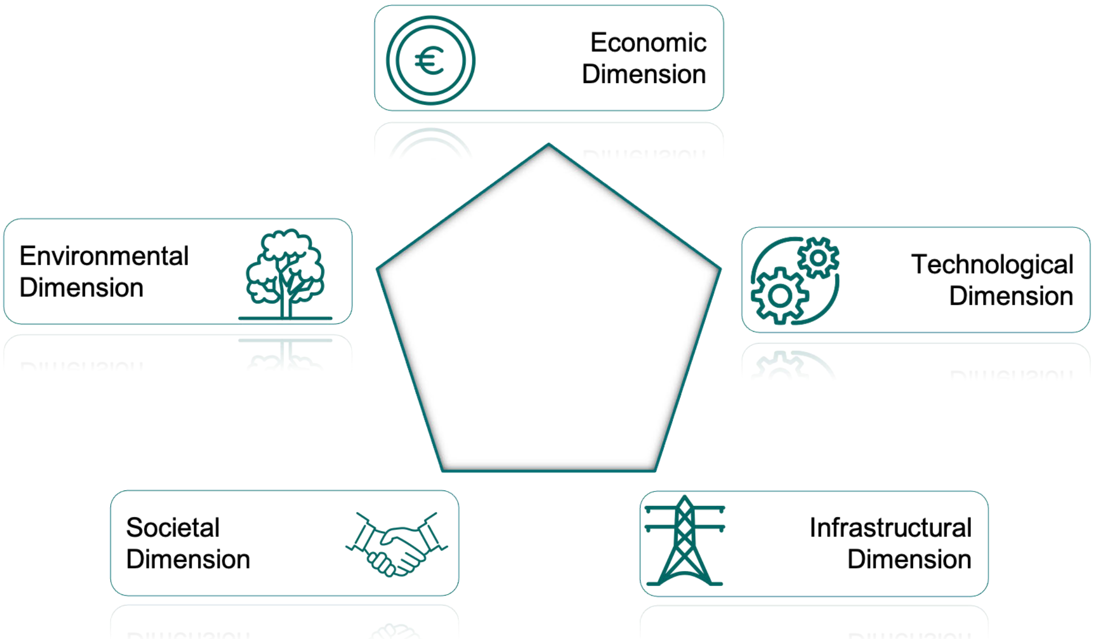



*Figure 8: Action fields to be addressed by policy responses (own figure)*

As regards the **economic dimension**, all technologies require additional upfront investment in order to align primary steel production with climate-neutrality. For instance, in the case of direct reduction, this does not only include technology-related investment, but may also factoring in plant-related adjustments for installing new pelletising plants necessary for feeding DRI-plants. For direct reduction, the use of iron ore pellets becomes more important; these could be produced on-site or purchased on the market (Draxler et al., 2021; Kempken et al., 2021). Increasing need for pellets will also affect operational costs of applying direct reduction technology, even though the central cost issue will without doubt be the costs of hydrogen purchases. Green hydrogen, in particular, will be more costly compared to other types of hydrogen, also due to its limited availability in the next years and its sensitivity to electricity prices (Ausfelder & Dura, 2019; Wuppertal Institut & DIW Econ, 2020). Electricity-related costs are also relevant for other technology options. Both, CCU and CCS as well as iron electrolysis require large amounts electricity and are, thus, sensitive to electricity prices and price spikes. CCU or the conversion of $CO_2$ into other products is linked to the availability of hydrogen (Agora Energiewende & Wuppertal Institut, 2019; Draxler et al., 2021). Since the secondary route relies massively on electricity, an expansion of the EAF-route (taking shares of the primary / BF-BOF-route) would also see a rising demand of electricity. In addition, limited scrap availability is likely to increase scrap prices (ESTEP, 2021). What also needs to be considered is the role of staff trained to apply new technologies (Kempken et al., 2021). Another issue will be the market uncertainty for green steel products and how, for instance, manufacturers of cars or appliances will take up green steel in the next years (Kempken et al., 2021). The cost dimension is a central issue because of the steel sector's exposure to international trade. Hence, steel producers are afraid of additional costs as their product may become uncompetitive in relation to countries with less strict regulation.

Considering the **technological dimension** for making primary steel through DRI-technology, it is relevant to investigate upon the integration of different processes including (on-site) hydrogen production, direct reduction and electric smelting, where hydrogen production is grid-optimized and flexible (De Santis et al., 2021). As regards green hydrogen production, proton exchange membrane electrolysis (PEMEL) is considered an important technology for grid-integration, but high temperature electrolysis (HTEL), which is able to make use of waste heat (possible also from steel plants) has better efficiencies. However, HTEL needs to be further researched upon, while PEMEL is closer to market deployment (IEA, 2019). Since iron electrolysis, applicable around the year 2050, needs substantial quantities of electricity, load-shifting potentials would need to be analyzed in-depthly before it is integrated into the power system (Agora Energiewende & Wuppertal Institut, 2019). However, it is generally considered to be suitable for integration in renewables-based electricity systems as operation temperature is low (Draxler et al., 2021). For the storage of $CO_2$ underground, safety and injection issues at storage sites need to be addressed (Umweltbundesamt, 2019). Scrap-based steel-making for primary or secondary production has a number of technical limitations, as well. These do not refer to the steel-making process as such but to the scrap availabilities. Some elements in scrap (such as cooper) cannot or can only hardly be removed in the electrical route, which is why secondary steel is often used in buildings (Kempken et al., 2021). Innovative technologies for automatic scrap property measurement (also using artificial intelligence) are known, but will be market ready (TRL 8) only around the year 2030 (Aydemir, 2021; De Santis et al., 2021).

For both, primary and secondary production, the expansion of **infrastructures** will be necessary. Since all technologies will need electricity for operation, the expansion of renewable energy capacities is a precondition for steel sector decarbonization. The hydrogen-route has the advantage that hydrogen can be transported via pipelines and imported, for instance, in liquefied form. However, in both cases, retrofitting existing pipelines and ports and building new ones is without alternatives and costly. However, addressing energy demands may only be one side of the coin, if $CO_2$ is captured. CCU or CCS would need transport modes (trucks, ships, short- to long-distance pipelines) to transport $CO_2$ to relevant destinations for further processing or long-term storage. In particular, with regard to $CO_2$, certain regulatory bottlenecks exist in Germany, that hinder the storage of $CO_2$ (Markewitz, 2018). It may also be worthwhile to reflect upon synergies with other sectors that may result from steel production. Like the aforementioned example of the (secondary) steel producer BSW, which facilitates waste heat to district heating networks, other opportunities may exist, for which infrastructure (upgrades) might be necessary.

The infrastructural build-up will have effects on the **environmental dimension**, for instance, if renewable energy farms, power grids or hydrogen- and $CO_2$ -pipelines are constructed in less-urbanised and more nature-oriented / protected areas. In particular, $CO_2$ -storage is feared to acidify ground water or result in seismic activity (Umweltbundesamt, 2019). Apart from that, it will be crucial to safeguard that all electricity capacities necessary to feed the steel industry will be additionally installed and, thus, do not withdraw limited renewables from other sectors. Moreover, the production of one kilogram of green hydrogen requires stochiometrically around 9 liters of deionized water (Beswick et al., 2021); water consumption is even considered to be higher in practice (Altgelt et al., 2021). While Germany is a „water rich“ country, the import of green hydrogen is indirectly also an import of water. In addition, using biomass (in combination with oxyfuel carbon capture and $CO_2$ -storage) will also necessitate to install standards that safeguard sustainable biomass production.

Challenges in the **societal dimension** of steel sector decarbonization may arise from price rises of end products and, more indirectly, public resistance linked with infrastructure developments, that is the new construction of power grids, pipelines or storage sites. Public opposition to onshore $CO_2$ -storage was already witnessed and resistance to grid expansion is ongoing in Germany (Markewitz, 2018). The move to turn to offshore storage-sites (as well as using CCS for process-related industrial emissions in contrast to focus on coal-power plants) has, however, reduced public headwinds and increased stakeholder support. Given that countries such as Norway seek to store $CO_2$ underneath the sea shows that the technology is available in principle, even though at higher prices in comparison to onshore storage (Thomas et al., 2021). Regarding costs, substantial increases of end products are not expected; for instance, first calculations suggest that prices for a car with a share of 30 % climate-friendly steel will result in additional costs of about EUR 40 (Agora Energiewende & Wuppertal Institut, 2019). First results of a research project suggest that the willingness to pay of end-users for climate-friendly steel products is higher than estimated market prices (Hirzel, 2021). However, public headwinds may also arise if biomass is used for steel production.

## 2.3 Conclusion - Implications and policy proposals with consideration of the time frame

Due to the challenges ahead, concerted policy action is planned by the German Government. The **Steel Action Concept** (SAC), published in 2020, outlines policy interventions possible for steel sector transformation towards climate-neutrality to address the economic barriers ahead (see figure x). It is noteworthy, that the Concept does not include any specification of emission reduction tragets of the steel sector.


*Figure 9: Pillars and initiatives for steel sector decarbonization (own figure based on BWMi 2020)*

As part of the European Union's "Fit for 55" package, which strives for 55% GHG emission reduction by 2030 compared to the 1990 baseline, the EU seeks to introduce the **Carbon Border Adjustment Mechanism** (CBAM) affecting imports from third countries including steel products. CBAM is supposed to "equalise the carbon price between domestic and foreign products, thereby limiting carbon leakage" and, in addition, motivating third countries to realise a carbon pricing regime (EPRS, 2022). Since steel producers in the EU are part of the European Emissions Trading System (ETS), they need to have emission certificates for every ton of $CO_2$ emitted. Until 2026, EU steel producers will also receive free allowances, but this free allocation is planned to be gradually phased out from 2026 onwards. Under the CBAM, importers of steel would have to purchase certificates reflecting the EU's carbon price to be paid if the same product had been produced in the domestic market. Implementation of CBAM is proposed in phases: beginning in 2023, steel importers would not have to pay CBAM certificates, but have to report GHG emissions including $CO_2$, N2O and PFCs. From 2026, importers would have to be authorized to import steel and obtain CBAM certificates (Appunn, 2020; EPRS, 2022).

At the EU-internal level, including in Germany, an innovative policy instrument currently discussed are **Carbon Contracts for Difference** (CCfD). Such Contracts support investors, including those from the steel industry, to realize low-carbon breakthrough technologies, which are (relatively) mature from a technological perspective but uncompetitive from an economic point of view. CCfDs include a project-based "strike price", which is above the market price for $CO_2$ (that is, higher than the ETS-price), agreed upon for ten years or more between the government and an industry investor. If the strike price is higher than the $CO_2$-price, the government pays the cost difference to the industry investor. The strike price also factors in the project-specific abatement-costs and increased operational costs, e. g. for green hydrogen (BMU, 2021; IN4climate.NRW, 2021; IREES et al., 2021). It has been estimated that between EUR 13 bn. and EUR 35 bn for such CCfD may be necessary to achieve steel sector transformation, also depending on other instruments of the policy mix including those that facilitate a green market for steel products (Agora Energiewende et al., 2021).

Upfront funding instruments include the **Innovation Fund** of the European Union and the Federal Government's **Decarbonization of the Industry Programme**. As regards the latter, industry projects seeking to store $CO_2$ underground are not eligible for funding (Kompetenzzentrum Klimaschutz in energieintensiven Industrien, 2022)

The SAC also notes that **public procurement** may pave the way for green steel, if climate-friendly steel is specifically considered for public contracts. A study suggests that public procurement of climate-friendly steel may realise emission savings of 150,000 t $CO_2$ in 2025, assuming that 5% of public steel demand is met by climate-friendly DRI-steel produced with a ratio of 90% natural gas and 10% hydrogen; increasing the quota to 30% and the hydrogen content in DRI production to 50% may result in 800,000 t $CO_2$ saved (Fischer & Küper, 2021).

Also discussed is a **quota for green steel in end-products** (BMWi, 2020). Such a quota would even enlarge the market for green steel products from a rather narrow public sector, as envisioned by a public procurement instrument, to private sectors. A compulsory quota of 30% green steel in cars is expected to only negligibly raise costs by around EUR 40 for end-users (Agora Energiewende et al., 2021).

*Text box 6: Offtake for a green steel market in Germany*

| |
|---|
| Even though discussions about costs of end-products due to green steel integration have not been settled yet, media report about cooperations between steel producers and manufacturers of end-products. For instance, the appliance manufacturers BSH and Miele have signed contracts with the steel producer Salzgitter to purchase green steel. While appliances are only a (relatively) small part of the steel sector's demand side, recent initiatives by the car producers BMW and Mercedes also bring the automobile sector on the table for green steel, which belongs to the largest demand side sectors regarding steel (see also Table x). Both companies seek to purchase green DRI-steel from a Swedish producer from 2025 onwards (Eder, 2021; Mercedes-Benz Group, 2021; Salzgitter AG, 2021b, 2021a). |

However, a trustworthy **label** or certification scheme would be necessary for both, public procurement and the quota on end-products. Otherwise, it could not be taken for granted that steel purchased is truly green. Since there is no such label available today, Salzgitter, for instance, contracted the TÜV-Süd, a certification body, which confirms that certain products made by the company are less emission intensive comparing primary steel production with the secondary route (Knitterschneidt, 2021; Müller-Arnold, 2021; Oberst, 2021).

Given that all technologies mentioned above rely on infrastructural upgrades, it will be crucial that **planning** will be orchestrated in a cost-effective manner. Applied research focuses on organizing the process to integrate the plans for electricity grids and pipelines (for natural gas and hydrogen) by establishing a system development plan preceding both, electricity and pipeline infrastructure planning (Deutsche Energie-Agentur, 2021b). Apart from that, it must be taken into account that substantial reinvestment will have to be made by 2030 in today's BF-plants: around 50% of the total primary production capacity of BF in the steel industry will reach the end of its service life by 2030 (Agora Energiewende & Wuppertal Institut, 2019). Hence, for a coherent planning of infrastructural upgrades and reinvestments in steel plants, a holistic approach needs to be found factoring simultaneous steps (in contrast to a sequential approach) (Grimm, 2021).

Since hydrogen is likely to be the key for transformation of the steel sector, infrastructure planning will be central aspect. But not only hydrogen-related transport issues will have to be solved, but also supply side issues. The **National Hydrogen Strategy** envisions a market ramp-up through developing electrolyser capacity of 5 GW by 2030; the new Government Coalition raised this target to 10 GW electrolyser capacity domestically. Moreover, hydrogen imports will become central, which is why the government supports international projects focusing on hydrogen production (e. g. Australia, Chile) (Federal Government, 2020, 2021). Generally, a hydrogen-related policy mix is another part of the discussion on steel stector transformation (Tholen et al., 2021). In this respect, the government also established a funding instrument called H2Global, which compensates for cost differences between green hydrogen import and market prices (H2Global Advisory, 2022).

Last, not least, the concept of an **steel sector decarbonization club** is currently discussed in Germany and beyond. Such a club is a grouping of least three actors (e. g. from the realm of government or private sector) from more than one country delivering a benefit exclusively to members of the club (“club good”). While there are several elements of such a concept in discussion, a valuable contribution of a “steel club” could be the realization of (ambitious) decarbonization targets among club members also to reduce uncertainty about technology, investments and future markets (Hermwille, 2019).

Apparently, Germany’s policy response for challenges in steel sector decarbonization focuses on the hydrogen pathway. Other technology options are less focused upon and, especially, (BE-)CCS, which is considered in some scenarios a relevant option around 2040 (Prognos et al., 2021), is less tackled policy-wise at the moment. Still, Germany’s Ministry for the Economic Affairs and Energy under the former government has worked on CCS and participates in a European coordination instrument for facilitating CCS (and CCUS) projects. The Industry Strategy 2030 mentions CCU and CCS briefly, stressing the role of RD&D (BMWi, 2019). Policy response for hydrogen-based steel making in Germany focuses on funding, either through investment support for pilot projects or through innovative instruments including CCfD, which may be implemented soon. Discussions on policy tools that focus on a green steel market (such as public procurement, quota, and labelling) are, although mentioned in the SAC, a bit retarded and likely to receive more attention in the next months to years.

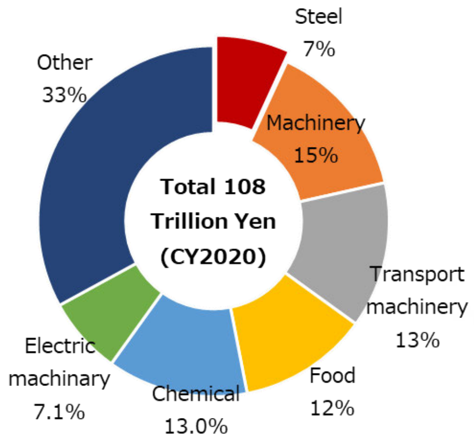
# 3 Japan

## 3.1 Industry overview

The steel industry is one of the major industries for the Japanese economy. The industry as a whole had sales of 19 trillion yen (about 146 billion euros) as of 2019, and was the fifth largest industry in terms of manufacturing market share after machinery, transport machinery, food, and chemicals. The steel industry provides as many as 300,000 jobs, including its wholesale segment. Steel also contributes significantly for Japan's acquisition of foreign currency, making it the fourth export product for Japan after automobiles, electronic parts such as semiconductors, and automobile parts.[1] As for export destinations of steel products, China accounted for 14% of the total export volume, followed by Thailand (14.1%), South Korea (13.8%) and the United States (6.1%) as of 2019.

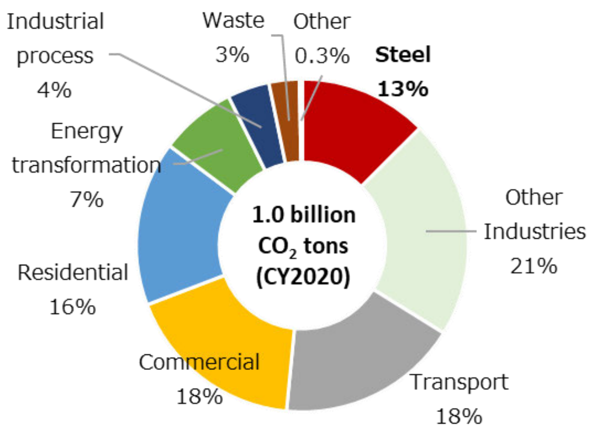
The steel industry’s contribution to the Japanese economy is large, but its contribution to the greenhouse gas emissions is also large. The steel industry emitted the largest amount of CO2 as a single industry (excluding electricity) in 2020, taking 13% of Japan's total CO2 emissions. In order to realize carbon neutrality in 2050, therefore, whether or not the steel industry can effectively cut its emissions is critically important.

[1] Japan Foreign Trade Council Inc, “Nihon no Boueki no Genjo to Kadai (Current status and issues of Japanese Trade)” December 2020. https://www.jftc.or.jp/kids/kids_news/japan/item.html. Accessed on 21 November 2021.




Source: Cabinet Office of Japan (2021)

*Figure 10 Industrial share in the GDP of manufacturing industry (in calendar year 2020)*




Source: National Institute for Environment (2021)

*Figure 11 $CO_2$ Emissions by industry (in calendar year2020)*

### 3.1.1 Major firms and revenues

In the Japanese steel industry, there are two types of steel-making companies, one that manufactures iron with a blast furnace and the other that manufactures steel with an electric furnace. This paper mainly focuses on steel companies using blast furnaces because its share over the total steel production is much larger and reducing the CO2 emission is much more difficult for a manufacturer with blast furnace.

There used to be a larger number of blast furnace steel companies in Japan, but as M & A between companies progressed, as of 2021, there are three major blast furnace steel makers in Japan as shown in Table 3.

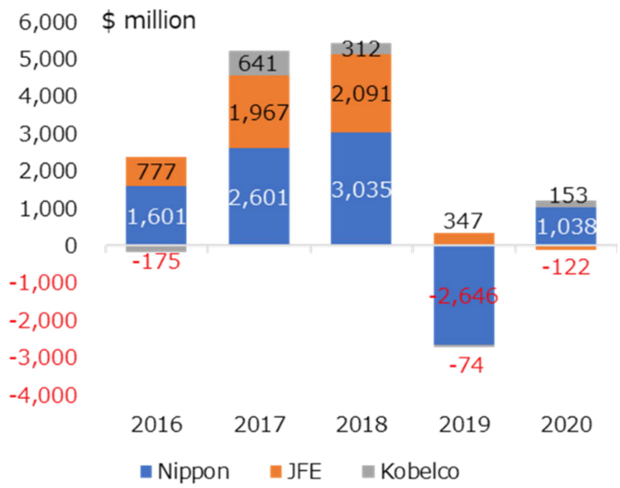
Table 3 Major Blast furnace steel maker of Japan

| Company | Nippon Steel Corporation | JFE Holdings Inc. | Kobe Steel, Ltd. (Kobelco) |
|---|---|---|---|
| Headquarters | Tokyo | Tokyo | Kobe / Tokyo |
| Employees (2020) | 106,226 | 64,371 | 40,517 |
| Ownership | Private (listed) | Private (listed) | Private (listed) |
| Sales (2020) | US$45,558 million | US$ 30,446 million | US$ 16,090 million |
| Operating income (2020) | US$1,038 million | (US$ 122 million) | US$ 152 million |
| Crude Steel Production (2020) | 37.7 million tons | 24.0 million tons | 5.8 million tons |

Source: Nippon Steel (2021)a; JFE Holdings (2021)a; Kobe Steel (2021)

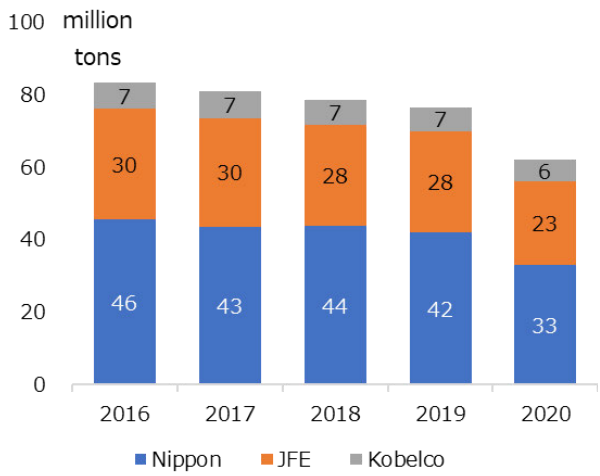
The business environment of each company fluctuates greatly from year to year. In the fiscal year 2019 (April 2019-March 2020), the global spread of the new coronavirus, which became more serious from the beginning of 2020, had a significant negative impact on the operation of the manufacturing industry. Because the manufacturing industry is a main customer of steel products, such negative impacts similarly caused a damage on the steel industry's business as well. In the fiscal year 2020 (April 2020 – March 2021), the industrial performance improved along with the recovery of the global economic activities.

The three major blast furnace steel makers are all 100% privately owned and publicly traded companies. Nippon Steel, in particular, is one of the world's largest steelmakers, ranked at third in terms of crude steel production. The three companies produced approximately 62 million tons of crude steel altogether, which accounts for 75% of Japan's total crude steel production in 2020. Crude steel production has been on a downward trend since before the spread of the coronavirus, due to factors such as troubles with manufacturing plants, the impact of natural disasters, and sluggish economic activity caused by the US-China trade dispute.




Source: Nippon Steel (2021)a; JFE Holdings (2021)a; Kobe Steel (2021)

*Figure 12 Operating incomes of major three steel maker in Japan*




Source: Nippon Steel (2021)a; JFE Holdings (2021)a; Kobe Steel (2021)

*Figure 13 Crude steel production by the three major steel companies in Japan*

### 3.1.2 Historical background

The history of Japan's modern steel industry dates back to 1857, when the first pig iron was successfully produced in Japan's first Western-style blast furnace in Kamaishi, Iwate Prefecture. In the past, steel mills were established in areas that had domestic production of iron ore or coal, but due to the increasing demand for steel and limited domestic resources, Japan became dependent on imports of both iron ore and coal. In addition, as explained shortly, Japan's steel industry is more dependent on exports than the steel industries of other countries. Most of the currently operated blast furnace exist on the Pacific coast of Japan, which makes them easier to import feedstocks and export their products

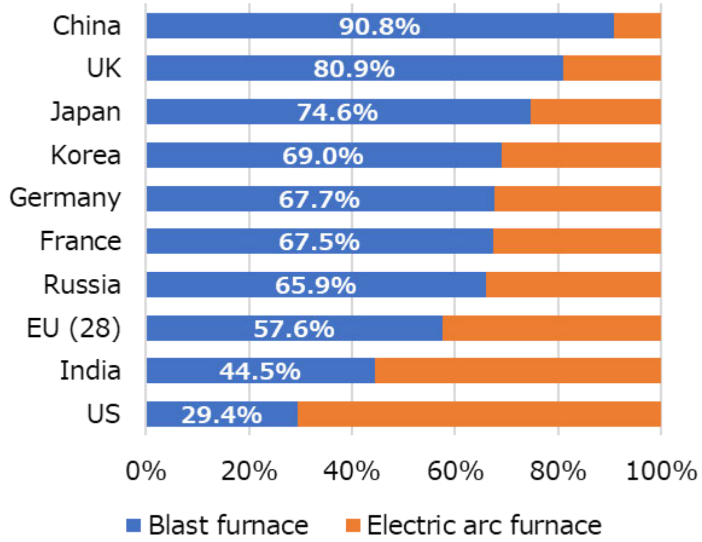
Remarks: Red=Nippon Steel; Blue=JFE; Green=Kobe Steel

Source: IEEJ

*Figure 14  Location of blast furnace in Japan*

### 3.1.3 Types of processes used

Japan's steel industry has a higher share of production using blast furnaces than other countries' steel industry. Figure 15 compares the share of blast furnaces and electric arc furnaces in the steel industry of various countries. The share of blast furnaces in Japan is about 75%, which is only lower than that of China and the United Kingdom and higher than those of other major countries including the United States and Germany. Japan's steel industry is highly dependent on blast furnace steelmaking, because it has a large demand of high-functional products such as high-tension steel for the automobile industry. In addition to this, in recent years, demand for steel frames for construction and other steel materials in Japan has been sluggish, resulting in a decline in demand for electric furnace products and consequently an increase in the share of blast furnace production. This market environment makes it difficult for the Japanese steel industry to decarbonize itself by “electrifying” its steel production process.



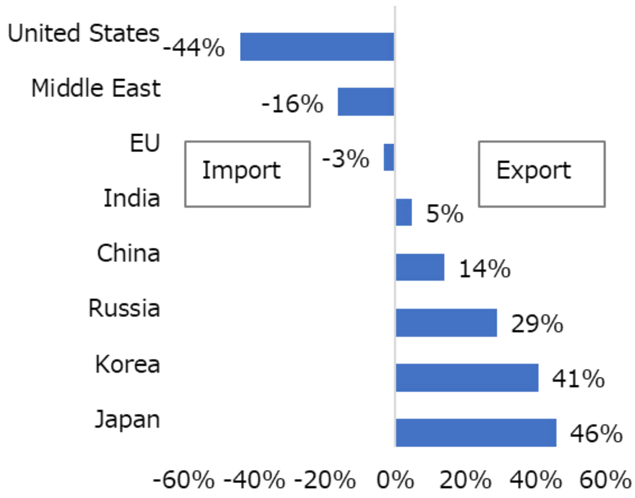

Note: Because the different reference the figures for Germany is different from the previous section.

Source: World Steel Association (2021)

*Figure 15 Share of blast furnace and electric arc furnace*

### 3.1.4 Other relevant factors affecting decarbonization of the steel industry

As shown in Figure 16, Japan’s steel industry exported 46% of the products it manufactured domestically to foreign countries as of 2018, making it more trade-dependent than other countries’ steel industry. This means that Japan’s steel industry is more heavily exposed to international competition, and in this sense, the increased costs associated with decarbonization will have a greater impact on its profitability and business structure.

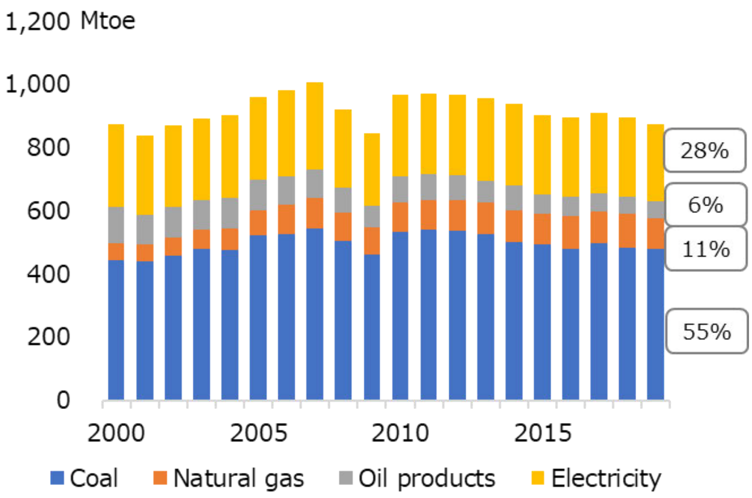



Source: International Energy Agency (2020) Iron and Steel Technology Roadmap

*Figure 16 Steel trade by major steel producers and users (2018)*

Partly because of its high dependence on the blast furnace, the Japanese steel industry is carbon-intensive also in terms of its energy consumed. As shown in Figure 17, more than half of the energy utilized in the Japanese steel industry is coal.

The Japanese steel industry has made serious efforts to reduce CO2 emissions from its operational activities. In particular, in 2005, the industry set a target of reducing CO2 emissions by 3 million tons compared to the business-as-usual case based on changes in product sales volume and the ratio of converters to electric furnaces. This target has been achieved as of 2019, mainly through the improvement of energy efficiency, specifically through the use of next-generation coke and the introduction of more efficient power generation equipment.

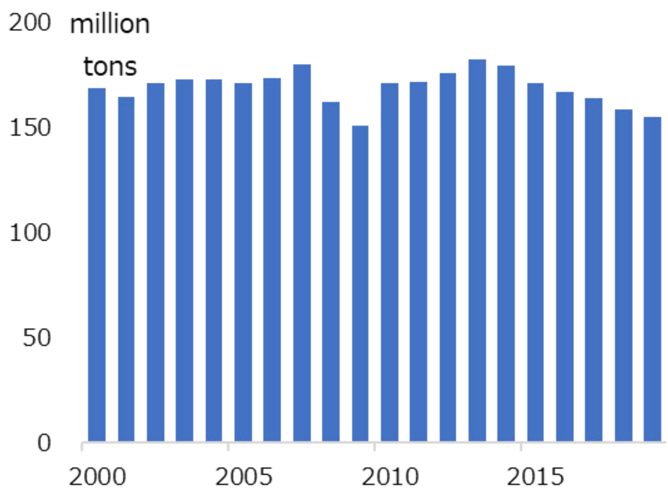



Note: the figure includes the consumption by electric arc furnace.

Source; The Institute of Energy Economics, Japan (2021).

*Figure 17 Energy consumption by the Japanese steel industry*

*Figure 18 $CO_2$ emissions from the Japanese steel industry*




Source: National Institute for Environment (2021)

*Figure 18 $CO_2$ emissions from the Japanese steel industry*

*Table 4 Measures to enhance efficiency in the steel industry*

**Next generation coke furnace**

| Company | Works | Year | Emissions reduction |
|---|---|---|---|
| Nippon | Oita | 2008 | -400 ktons-CO2/yr |
| Nippon | Nagoya | 2013 | -100~-200 ktons-CO2/year |

**Installation of efficient power generation unit**

| Company | Plant | Year | Type |
|---|---|---|---|
| Kobelco | Kakogawa | 2011 | Gas turbine combined cycle |
| Kimitsu Kyodo | Kimitsu | 2012 | Advanced combined cycle |
| Kasihma Kyodo | Kashima | 2013 | Advanced combined cycle |
| Wakayama Kyodo | Wakayama | 2014 | Advanced combined cycle |
| Oita Kyodo | Oita | 2015 | Advanced combined cycle |
| Kobelco | Kakogawa | 2015 | Gas turbine combined cycle |
| JFE | Chiba | 2015 | Gas turbine combined cycle |
| Nippon | Kure | 2017 | Boiler turbine |
| JFE | Ohgishima | 2019 | Gas turbine combined cycle |
| Fukuyama Kyodo | Fukuyama | 2020 | Gas turbine combined cycle |

Source: Japan Steel & Iron Federation (2021)

## 3.2 Decarbonization roadmap

### 3.2.1 Mid- and long-term emissions reduction goals

The Japanese government has set a carbon neutrality target for 2050, and the steel industry, a major emitter in Japan, has also set a carbon neutrality target as of the same year. Nippon Steel, JFE, and Kobelco all declared their targets for 2050, which is consistent with the Japanese government's target in this respect.

While the end game of the three companies is the same, there are nuanced differences in the medium-term targets in their emissions reduction roadmaps. Although the Japanese government has set a target of 46% reduction from the 2013 level by 2030 for the entire country, the targets set by blast furnace steel makers for 2030 are lower than the nationally-set target. Specifically, Nippon Steel set a target of 30% reduction, while JFE aims to achieve 20% reduction, and Kobelco says it will reduce emissions by 30-40% reduction (the base year for all of the three targets is 2013).

### 3.2.2 Assumed decarbonization actions and elaboration of emissions reduction path

*Decarbonization actions by each steel company*

Nippon Steel has set a medium-term goal of reducing emissions by 30% from 2013 levels. The company plans to reduce CO2 emissions from its existing blast furnace and converter processes and develop an efficient production system by introducing the technologies developed in the COURSE50 program (to be explained later). The long-term carbon neutrality goal by 2050 will be pursued by the technologies such as the mass production of high-grade steel in large electric furnaces, hydrogen reduction steelmaking, and carbon offsetting measures through the adoption of carbon capture, utilization, and storage (CCUS) technologies.

*Table 5 Technological issues and required external environment*

| Technology | Technological issues | Required external environment |
|---|---|---|
| High-grade steel manufacturing technology in a large Electric arc Furnace (EAF) | • Quality restrictions due to impurities in scrap or nitrogen contamination during melting<br>• Scale of facilities and productivity need to be improved. | • Cost competitive carbon-free electricity |
| Hydrogen injection into BF | • Development of technology to inject a large amount of hot flammable gas into BF<br>• Ensuring maximum gas permeability for stable reaction and melting with less coke in the BF<br>• Scaling up technology to simulate a large-scale BF | • Realization of Carbon Capture and Utilization (CCU) and Carbon Capture and Storage (CCS)<br>• Large volume of carbon-free hydrogen supply |
| 100% hydrogen use in direct reduction | • High-hurdle unproven processes that have never been demonstrated before<br>• Technologies for blowing a | • Large volume of carbon-free hydrogen supply |

| | | |
|---|---|---|
| | large amount of preheated flammable gases at high temperature into the furnace, and expanding ores applicable to the hydrogen process | |

Source: Nippon Steel (2021)b

The company states that there are technical challenges to overcome in each of these decarbonization efforts, and that external conditions must be in place to realize the carbon neutrality (Table 5). Furthermore, the production of such "zero-carbon steel" will require a significant amount of research and development (R&D) expenditures, large upfront capital investment, and higher operating costs associated with the use of carbon-free hydrogen and carbon-free electricity, which could more than double the current cost of producing crude steel as of today (Suzuki, 2021).

As for JFE Steel, the medium-term goal is to reduce emissions by 20% from 2013 levels as of 2030, and to achieve Carbon Neutrality as of 2050. Compared to Nippon Steel, the reduction targets for 2030 are moderate. As a unique attempt by JFE, the company plans to use artificial intelligence (AI) and data science to enhance the steel production productivity. The company also plans to expand the use of scrap materials and improve energy efficiency and produce syhthetic methane from capture $CO_2$ from the steel making process as explained later. As a long-term action, the company aims to adopt hydrogen in the steelmaking process by participating in the Ferro coke development plan and COURSE 50 (to be explained later) as future technology development.

Ferro coke is a substance consisting of low-grade coke and iron ore, which can realize the reduction process with a smaller amount of coke. JFE has been working on this technology development as a project supported by New Energy and Industrial Technology Development Organization (NEDO), a Japanese government organization, since 2017. The company is currently constructing a production facility for ferro coke with an annual production capacity of 300 tons at the company's Fukuyama Steel Works. By utilizing this ferro coke, it is expected that the amount of energy used in the steelmaking process will be reduced by 10% by 2023.

In addition, the company plans to proceed with technological development of hydrogen direct reduction ironmaking and CCUS as further R&D areas.

Kobelco set a goal of achieving Carbon Neutrality by 2050 and, as a mid-term target, set a reduction target of GHG by 30% to 40% compared to 2013 by 2030. This target is more aggressive than the preceding two companies. The specific amount of CO2 emission to be reduced is 61 million tons as of 2030 compared to 2013. The company's measures to reduce CO2 emissions are further improvement of existing energy efficiency technology, scrap utilization, AI-based furnace operation, and technological development for the future production of high-quality steel materials using electric arc furnaces. The company plans to expand its own MIDREX® technology as a future low-carbon measure in the transitional period. This technology is a method of direct reduction using natural gas, and is currently used in 60% of the world's direct reduction steelmaking.

In addition, Kobelco has an Independent Power Producer (IPP) business on the premises of its steelworks, which supplies electricity to neighboring areas. The company has a plan to adopt biomass or clean ammonia as a co-firing fuel to reduce emissions. In the future, the company's power generation business segment is expected to process carbon-neutral methane and 100% ammonia-fired power generation.

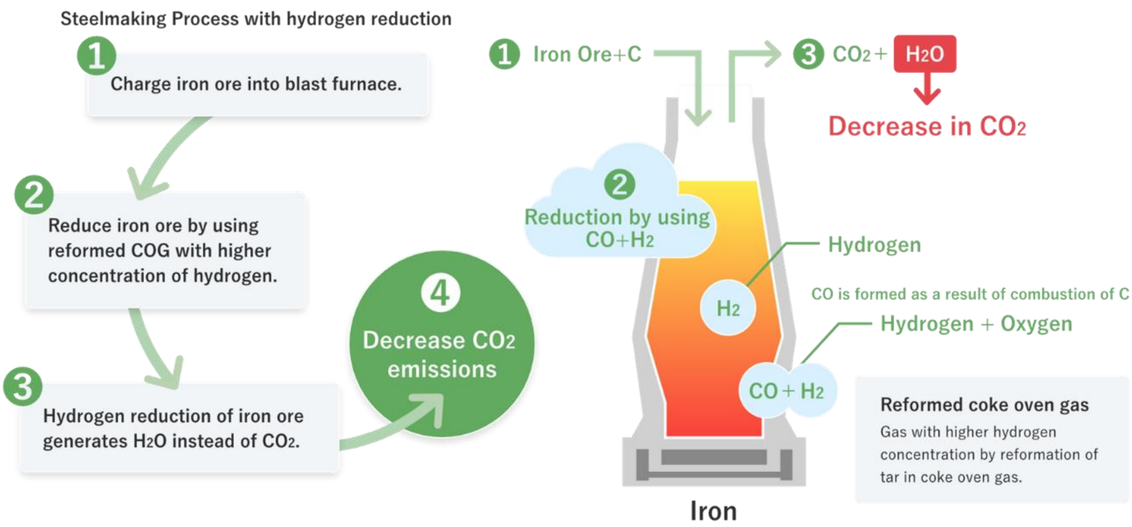
*Decarbonization actions by public-private collaboration*

While each steel company intensively works on its on decarbonization actions, the Japanese government supports a public-private collaboration in developing core technologies to realize carbon neutrality in the steel sector. Under such objective, a collaboration framework called COURSE50 (CO2 Ultimate Reduction System for Cool Earth 50) was established by New Energy and Industrial Technology Development Organization (NEDO) and four Japanese steel and engineering companies.


Source: Author based on COURSE 50 (2021)a

*Figure 19 Organization of COURSE50*

The objective of COURSE50 project is to examine the emission reduction measures from the existing blast furnace, and the major focus among them is the utilization of hydrogen in the blast furnace. Utilizing hydrogen with ordinary cokes in blast furnaces is being examined in the project.



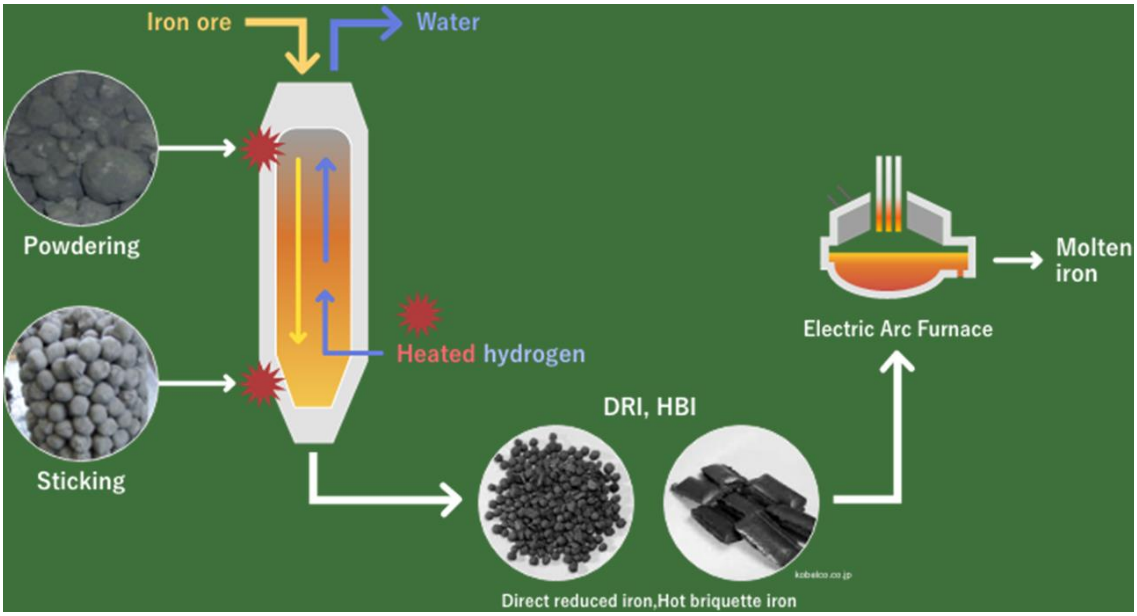

Source: COURSE 50 (2021)b

*Figure 20 Utilization of hydrogen at blast furnace*

Another major area of research in COURSE50 project is the capture of $CO_2$ generated during the reduction process. For capturing $CO_2$, technology of chemical absorption is adopted. Because removing $CO_2$ from the chemical material in this process requires a large amount of heat, utilizing the heat generated in the steelworks for the $CO_2$ removal is currently being studied. R&D activities are undertaken to develop a chemical solution that can absorb as much $CO_2$ as possible per unit volume, and to realize more energy-efficient $CO_2$ extraction from the absorbed solution.

Regarding the technology that utilizes hydrogen in the blast furnace process, hydrogen is assumed to be obtained as a by-product of the steel-making process. "Super COURSE 50," which is set up as an extension of COURSE50 project, aims to utilize hydrogen obtained from outside the steel works besides such internally generated hydrogen. While, in COURSE50, due to the limitation of hydrogen supply amount, only 30% reduction of $CO_2$ is done together with the reduction amount by CCS, in this Super COURSE50, the reduction rate is further increased by utilizing external hydrogen. This research program is expected to carry out research activities up to 2040 and to be put into practical use after that.

In addition to these efforts, the direct reduction process is expected to become one of the decarbonization technologies in the future. Compared to the blast furnace route, which is currently the mainstream steel making process in Japan, the direct reduction route has various challenges, such as low energy efficiency because it requires separate furnaces for reduction and melting, and restrictions on raw materials because impurities cannot be removed. However, if hydrogen can be used as a reducing agent, there is a great merit that iron can be produced without generating $CO_2$.




Source： Japan Iron and Steel Federation (2020)

*Figure 21 Hydrogen Direct Reduction*

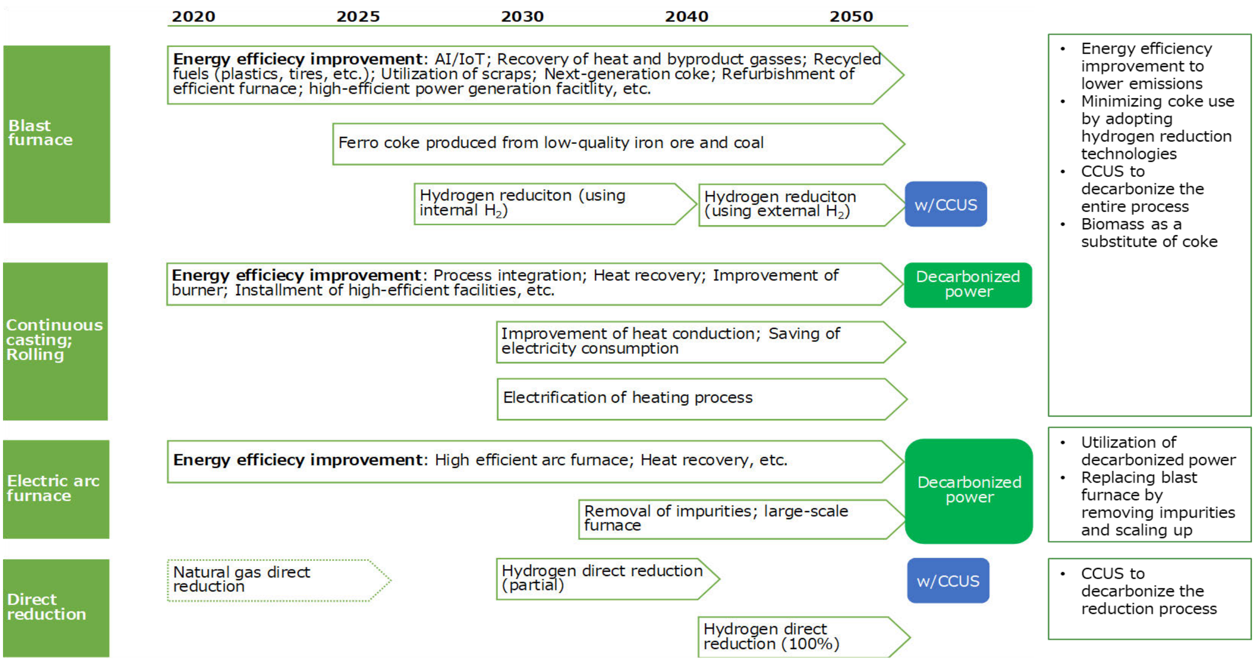
Technological development is also being conducted for capturing CO2 generated in the reduction process and converting it into fuel for use. This is one of the carbon capture and utilization (CCU) technologies that reuse CO2. Currently, JFE is leading the development of a technology called methanation that converts CO2 into methane. Methane produced by this technology can be used in the same way as ordinary natural gas. If the CO2 generated from the reduction process is converted to methane and used as a fuel for steel making, it can be used as a carbon-neutral fuel that does not increase CO2 in the atmosphere (JFE Holdings 2021)b.

### 3.2.3 Menu of decarbonization technologies

As a roadmap with specific required technologies to decarbonize the steel industry, the Japanese government (Ministry of Economy, Trade and Industry) set up a roadmap. In the segment of blast furnace in the roadmap, in addition to the technologies explained above, technologies of continuous casting and rolling, energy saving and high efficiency improvements are also included. Other relevant technologies include utilization of waste heat and duplicated gas in the steelmaking process, combustion of waste, and further improvement of energy efficiency by utilizing artificial intelligence (AI).

In the segment of electric arc furnaces, utilizing decarbonized power sources (renewable energy / nuclear power), removing impurities contained in scrap, and increasing the size are included as a specific measure.

With regard to hydrogen direct reduction steelmaking, which will occupy a very important position in the field of future technological development, it is mentioned that a direct reduction furnace that partially uses natural gas may be able to achieve decarbonization in combination with CCUS.




Source: Ministry of Economy, Trade, and Industry (2021) translated by author

*Figure 22 Roadmap prepared by Ministry of Economy, Trade, and Industry*

In advancing such decarbonization technology, not only technical feasibility but also economic feasibility is equally important. Pertaining to the adoption of hydrogen, it is estimated that the cost of hydrogen supply needs to be as low as 8 yen per normal cubic meter (Nm3) ($1.5/MWh) (Nippon Steel 2021b). Because the current Japanese government target of hydrogen supply as of 2050 is 20 yen per Nm3, there is still a wide gap between them. Furthermore, it is necessary to secure a large amount of hydrogen at such a competitive cost, and according to Nippon Steel's estimation, a total of 75 billion Nm3 (266TWh) of hydrogen is required to secure the current production volume.

### 3.2.4 Major challenges to realize the roadmap

Decarbonization of the Japanese steel industry has various challenges. The first is the promotion of technological development. Although all three blast furnace manufacturers have set carbon-neutral targets for 2050, they have not yet developed the necessary technologies. In particular, hydrogen reduction steelmaking, which does not generate CO2 during reduction, is regarded as an indispensable technology for decarbonization of the steel industry not only in Japan but also in the world. Yet, there are still many technical issues to be addressed to make it commercial use. For this reason, it is necessary to continue technological development through public-private partnerships from a long-term perspective, such as COURSE 50.

The next challenge is to secure competitively-priced clean hydrogen. Even if a technological breakthrough of hydrogen reduction steel-making is realized, it will be difficult to commercialize the technology unless the clean hydrogen required for that purpose is available at a stable and sufficiently affordable price. As for clean hydrogen, there are blue hydrogen produced by utilizing CCUS from fossil fuels and green hydrogen produced by electrolyzing water with electricity obtained from renewable energy. If it is clean enough, both types (or “colors”) of hydrogen should be a source of such hydrogen for steel making. It is often noted that blue hydrogen derived from fossil fuels is cheaper at the moment, but if the cost of power generation by renewable energy and the cost of water electrolysis equipment are greatly reduced in the future, the cost competitiveness of green hydrogen will be improved. Developing production capacities for competitive and sufficient volume of clean hydrogen is another critical condition to realize the decarbonized steel sector.

The third challenge is to secure clean electricity at competitive price. Compared to the blast furnace route, the electric arc furnace route is easier to realize decarbonization. However, since a large amount of electric power is used in the steelmaking process using an electric furnace, it is also necessary to secure a sufficient amount of zero carbon electric power derived from renewable energy or nuclear power .

Finally, it is also critical to put CCUS into practical use. CCUS can be broadly divided into two technology types, CCU and CCS. For CCU, it is expected that the technology for producing synthetic methane using CO2 replicated in the reduction process will be put into practical use. Since this technology goes through the process of extracting carbon from the captured CO2 and combining it with hydrogen, it is necessary to secure clean hydrogen that is cost-competitive as described above in addition to the recovery of CO2. For CCS, a location to store the captured CO2 must be secured in addition to low-cost CO2 capture technology. In Tomakomai City, Hokkaido, a demonstration experiment to store CO2 in the underground aquifer has been conducted. In addition to such a promising storage destination in Japan, the development of a CO2 transfer network that anticipates CO2 storage overseas in the future.

# 4 Conclusion

## 4.1 Common ground

Observations until the previous section reveal several commonalities and differences in the decarbonization effrots of both countries's steel industry as summarized in the following table.

*Table 6 Commonalities and differences in the decarbonization actions by German and Japanese steel industry*

| Commonalities | Differences |
|---|---|
| • **All major companies have mid-term (2030) targets and aim for long-term full decarbonization**<br>• **Utilization of hydrogen as fuel**<br>• **Direct reduction by hydrogen**<br>• **Carbon, capture, utilization, and storage (CCUS)**<br>• **Biomass as fuel**<br>• **Electrification (raising the share of electric arc furnace)**<br>• **GHG Reduction targets**<br>- All major companies have mid-term (2030) targets and aim for long-term full decarbonization | • **Public-Private Partnership (J)**<br>• **Products by CCU application**<br>- Chemical (G) vs Methane (J)<br>• **Direct reduction by natural gas (G)**<br>• **Bio energy carbon capture and storage with oxyfuel (G)**<br>• **Utilization of ferro coke (J)**<br>• **Major sources of hydrogen**<br>- Domestic green H2 (G) vs Blue and green H2 of both domestic and import (J)<br>• **Major sources of zero emissions electricity**<br>- Renewable (G) vs various generation sources incl. renewable, nuclear and hydrogen/ammonia (J) |

*Remarks: (G) stands for the case for the German industry only; (J) stands for the case for the Japanese industry only*

*Source: authors*

Both countries share a set of common issues in order to decarbonize the steel sector. Companies in both countries have set up emission reduction targets with frontrunners on both sides. The Japanese steel producer Kobelco pursues the ambitious target to reduce emissions between 30% to 40% by 2030 (compared to 2013) and the German company Salzgitter strives for a 50% emission reduction by 2030 (compared to 2018 levels). Overall, the average level of companies' targets for 2030 is comparable between Germany and Japan. In addition, all major companies in both countries have pledged to become carbon-neutral by 2045 or 2050 (in Germany) or 2050 (in Japan).

One of the key technologies considered in Japan and Germany is the application of hydrogen and direct reduction of iron, and both countries acknowledge the role of low-carbon hydrogen. Likewise, both countries share the challenge of higher costs associated with hydrogen-based steel relative to conventional production. All major companies in Germany and Japan put more or less emphasis on hydrogen-based steel making as a means to decarbonize their production in the future. In Germany, ArcelorMittal already operates a DR-plant, with other German players following suit. The fact that all of the aforementioned scenarios modeled for Germany assume an expansion of DRI-based steel by 2030 and 2045 suggests that hydrogen will play a substantial role in low-carbon steel making in the country. Likewise, in Japan, the three largest steel companies in Japan all plan to make use of hydrogen for future steel making.

Apart from that, CCUS is another technology pathway. In Germany, ThyssenKrupp facilitates metallurgical gasses to the chemical industry for production of certain chemical products. In Japan, JFE currently develops a methanisation process based on $CO_2$ captured at the blast furnace and, then, the methane is used as a fuel for steel making.

As for Germany, biomass has not been part of the SAC and is not discussed very intensively in public debates. Still, one of the aforementioned scenarios aligned with Germany’s revision of the Climate Protection Law, assumes that biogenic syngas might also be used in future primary steel production. In Japan, the steel producer Kobelco plans to adopt biomass as a co-firing fuel.

In Japan, the secondary route is, for instance, pursued by Nippon Steel and Kobelco in order to produce high-grade steel. In Germany, all scenarios discussed assume a higher share of EAF-production by 2030 and 2045. The use of artificial intelligence to optimize plant operation appears to be of some interest in both countries to generate additional emission savings. In both countries, the availability (and quality) of scrap is and will be a bottleneck for expanding the EAF-route and will be linked to the question of future steel demand, e. g. in the construction sector, which typically makes use of larger quantities of secondary steel. For instance, if buildings will rely to a larger extend on sustainable biomass, the demand for recycled steel might be less urgent (assuming that demand does not increase in other sectors).

From a policy perspective, Germany and Japan established long-term emission reduction targets, but these have not been broken down to specific steel sector targets in neither countries. For Germany and Japan, an increase in electricity production for and due to low-carbon steel is expected. This also results in a shared problem of price-competitiveness of steel produced domestically in these countries *vis-à-vis* other countries. Both Governments are actively involved in supporting research and development efforts in the steel industry

## 4.2 Differences

As mentioned above, the steel industry's decarbonization roadmaps of both Germany and Japan have much in common, but there are some nuanced differences in the assumed steel-making technologies and other non-technologies areas.

The first difference is the way of public-private collaboration. In Japan, a government-industry collaboration (COURSE50) is formed by a government organization (NEDO) and major steel companies and has been effectively operated to develop "core" decarbonization technologies such as hydrogen utilization or carbon capture process. Since COURSE50 program was expanded to Super COURSE50 in 2020, the close collaborative frame is likely to remain as a key platform for the Japanese steel industry's research and development (R&D) efforts toward carbon neutrality. German steel industry also has an access to sufficient public fund, such as EU's Innovation fund and the federal government's Decarbonization of the Industry Program. Compared to the Japanese industry, however, German steel companies seems to pursue their R&D rather independently. To be sure, in both countries, recognizing the significance of the steel industry's decarbonization, governments have a strong interest and commitment to the industry's R&D efforts. What seems different is the approach of their involvement to the industry's decarbonization efforts. This differed approach may reflect the tradition of both countries' industrial policy toward the steel industry.

Second, while both German and Japanese steel industries plan to apply carbon capture and utilization (CCU) technologies to their blast-furnace steel making plants, the assumed final products are different. Japanese steel industry seeks to produce synthetic methane from capture carbon with green hydrogen. JFE Steel Corporation (2021) has formed a consortium with Nippon Steel and other Japanese firms to develop a system to supply the produced synthetic methane as a shipping fuel. German industry, on the other hand, plans to produce chemical products. Thyssenkrupp (2021) in Germany is developing CCU technology called Carbon2Chem®, which produces chemical products from capture carbon from the steel-making process. Japanese industry aims to build a "carbon-recycling" process by using the synthetic methane produced from captured carbon while German industry seeks to fix the captured carbon for a longer time as converting it to chemical products such as plastics.

Third, there is a greater interest in the direct reduction steelmaking using natural gas as in the German steel industry, while hydrogen is deemed as a primary reduction agent in the Japanese steel industry. The direct reduction steelmaking process using natural gas has an advantage that it will be easier to shift to hydrogen reduction steelmaking by blending and raising the ratio of hydrogen at later stage. In the Japanese steel industry, Kobelco's MIDREX® process is also a direct reduction technology that uses natural gas as a reducing agent, but there are no applications in Japan. This is thought to be because most of natural gas is imported in the form of LNG in Japan, and its price is relatively high.

Fourth in the scenario of German steel industry's decarbonization by Öko-Institut and Wuppertal Institut (2021), the possibility of technology combining biomass, oxyfuel fuel combustion, and CCS is mentioned. By burning biomass such as wood chips, synthetic gas is produced and used in the iron making process, while by utilizing oxyfuel in the combustion process to efficiently capture CO2. The capture CO2 is then transported and stored underground. Since the captured and stored CO2 is biogenic, this technology can achieve negative emissions. Given the fact that eliminating the entire emissions from steel-making process is very challenging, this technology will greatly help the industry to achieve the goal by offsetting the residual carbon emissions.

Fifth, what Japanese steel industry more closely works on is next generation coke. Ferro coke is an innovative reduction agent to improve the reduction rate of iron ore and cut CO2 emissions. While the technology may be utilized for the transition period as it does not necessarily lead to zero emissions. But it can materialize significant reduction of CO2 emissions and is expected to play an important role to achieve the industry's mid-term reduction target.

Sixth, while hydrogen supply is expected to play a critical role for both countries' steel industry, procurement policy of hydrogen have nuanced difference between the two countries. Although the both countries' steel industry plan to utilize both green and blue hydrogen, German steel industry pays more attentions to green and domestic hydrogen while Japanese steel industry is more flexible toward the colors and the geographical sources of hydrogen. This derives from the difference of availability of hydrogen sources. German industry has better access to domestic and competitive renewable energy resources such as wind and can import renewable electricity from neighboring countries such as the Netherlands and Denmark by grid. Japanese industry, on the other hand, has limited access to domestic renewable energy due to its inherent resource constraints and lack of international power grid connection. Given its higher share of export dependence, furthermore, the Japanese steel industry is very sensitive toward the cost competitiveness and specifies a particular cost target of clean hydrogen supply for zero-carbon steel (8 Yen/Nm3) ($1.5/MWh), while seemingly German steel industry does not have such a target.

Seventh, although this may not be a "difference" in a strict sense, the two countries' industries face different types of challenges to secure zero-emissions electricity. Both countries' industry consider electrification of their steel-making process with zero-emissions electricity is one of their decarbonization options. Since Germany plans to phase out nuclear power generation by 2035, renewable electricity will be the primary source of electricity. Securing sufficient volume of such renewable electricity at competitive cost will be a big challenge for them. Japan, on the other hand, plans to keep utilizing nuclear power generation, but it has not been able to restart its idled nuclear units since the great earthquake in 2011. Promoting the restart of nuclear units whose operational safety is confirmed will be critically important to make such electrification of steel making process more plausible.

# 5 Recommendations

## 5.1 Germany

Germany ambitiously strives for climate-neutrality in 2045. For this, the decarbonization of the steel sector will be essential. Likewise, it will be crucial to not undermine the industry's competitiveness by increasing the costs of German steel in comparison to competitors. For this, the German Government plans to set up a comprehensive policy package that seeks to bring climate policy and industrial needs together, including CCfDs and possibly CBAM, as well as green steel labelling and procurement. These plans need to be further pursued and realized effectively. It may also include the propagation of international alliances not only in the steel or energy intensive industries sector (similar to the idea of climate or decarbonization clubs), but also regarding energy or hydrogen partnerships safeguarding the reliable supply of a new and green energy carriers.

To some extend, policy can also foster technology readiness. While DRI-technology is relatively mature, other technologies may deserve R&D support (e.g. iron electrolysis, high temperature electrolysis, CCU), also to reduce costs. This is also true for the secondary route, where several hurdles are in the way for increasing the share of recycled steel including the availability and quality of scrap. Since the departure from the BF-BOF-route will result – upstream – in an increased appetite for electricity and import and transport infrastructures for hydrogen, and – downstream – potentially in large-scale $CO_2$ logistics (not available in Germany, so far), the German Government together with other relevant stakeholders must make progress regarding the cost-effective infrastructure development, also to unleash investments in the steel sector and to provide planning security. In Germany infrastructure deployment may facilitate public headwinds, often known as the "not-in-my-backyard" phenomenon. It will be crucial to balance, in advance, economic interests of steel and infrastructure providers against interests of local communities.

Another rather societal issue is to mitigate social hardships, which, for instance, means that steel-intensive products must remain affordable for low-income households. Society may also perceive green steel (and related support) as a worthwhile undertaking, if benefits feed back to the people. Hence, training the workforce for green steel production could contribute to gain societal support. Moreover, the auxiliary infrastructures of green steel in Germany and beyond have spatial requirements, which might also undermine other environmental concerns; for instance, water-electrolysis using sea water results in salt brine, which may affect local / maritime biodiversity. Such issues must be taken into account.

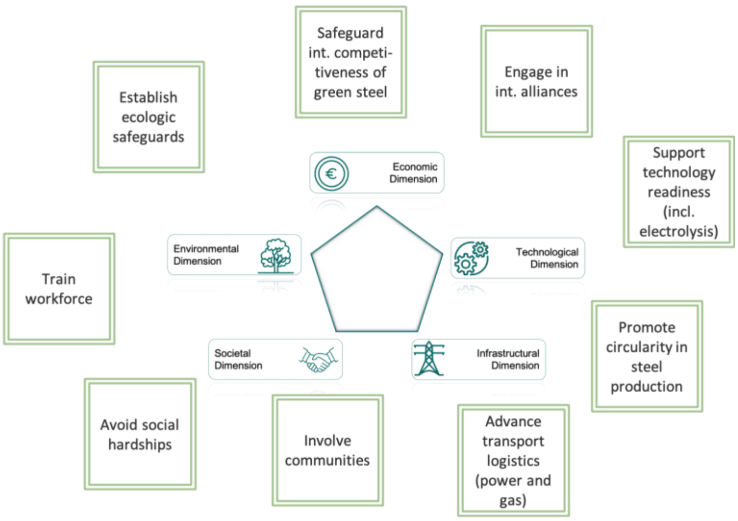



*Figure 23: Policy recommendations for accompanying green steel deployment in Germany*

## 5.2 Japan

### 5.2.1 Support for innovative steel-making technology

The first recommendation is to provide policy support to the development of innovative technology with an awareness of the time frame for achieving carbon neutrality by 2050. The technology that can completely reduce CO2 emissions from the steelmaking process has not yet been established on a global scale. To overcome such a challenging issue, there is a limit to what the private sector can do on its own, so some form of government support is needed. The core technologies for decarbonization are direct reduction ironmaking using hydrogen and CCUS, and it is necessary to develop these technologies with the timeframe until 2050 to be effectively utilized in the steel-making process. The study to use hydrogen in the steelmaking process has already been launched by COURSE50 and Super COURSE50 programs, and it will be necessary to expand these existing efforts to direct hydrogen reduction technology as well. With regard to CCUS, the development of CO2 capture technology has been in COURSE50, but in the future, technologies to convert the captured CO2 into fuels and other products, and arrangements to transport and store the CO2 underground will be required.

In February 2021, the Japanese government announced the establishment of a Green Innovation Fund with a total of 2 trillion yen (US$17billion). Given its weight in the Japan's macro economy and the large share of CO2 emissions in Japan, the decarbonization of the steel sector should be places as a high-priority goal for achieving carbon neutrality in 2050, and the fund should be effectively utilized in the endeavor.

### 5.2.2 Competitive clean hydrogen

The second recommendation is the policy to ensure cost-competitive clean hydrogen supply. A major source of such clean hydrogen is expected to be green hydrogen produced from electrolysis process based on the domestic renewable energy. In order to ensure sufficient supply of hydrogen for steel making process, cost reduction of electrolyser as well as the renewable electricity must be pursued through continuous policy support. As a long-term effort, the technology development to produce hydrogen from nuclear energy, which is currently conducted by Japan Atomic Energy Agency should also be continued (Nagai 2021).

The supply of hydrogen from these sources, however, is likely to be costlier and smaller in volume than the supply of imported blue hydrogen that is produced from natural gas with CCUS application overseas. Currently, the introduction of blue hydrogen in the form of ammonia is scheduled to begin in the second half of the 2020s, and the use of hydrogen in Japan's power generation sector is expected to accelerate. Such an expansion of hydrogen use may well have a positive impact on the cost of supplying hydrogen for the industrial sector including the steel industry. For the time being, ammonia in the power generation sector will be supplied directly from overseas to power plants, but in order to further reduce costs, efforts are being made to reduce overall costs by developing large hydrogen import hubs and using large hydrogen tankers. A steel mill located in the proximity to import hubs will be able to procure hydrogen competitively by receiving hydrogen supply directly through pipelines. Securing a competitive supply of hydrogen to steel mills will be enabled by coordinating with other sectors and industries, and thus the coordination by the central government as well as the local government to facilitate such infrastructure will be important.

### 5.2.3 Operationalization of CCS

Thirdly, the environment to apply CCS technologies to the steel-making process needs to be developed. This is because there may be a limit to the amount of CO2 that can be absorbed by CCU domestically. As an effort to promote CCS technologies, a demonstration test of CO2 storage has already been conducted in Tomakomai, Hokkaido. In the future it will be necessary to secure sufficient locations where CO2 can be stored stably in addition to Tomakomai and to construct a CO2 transportation network for this purpose. Naturally, this cannot be done by the steel industry alone. Hence, so it will be necessary to coordinate with other industries such as the shipping industry to transport CO2 and the oil industry to store CO2 underground. The government is expected to play a major role to coordinate these various industries.

In addition, if the storage capacity in Japan is not sufficient, Japan may need to consider CO2 storage overseas. In this case, as a new form of resource diplomacy, the government will coordinate with overseas countries that have many geological formations (depleted gas fields and aquifers) suitable for storage. It will also be necessary to coordinate with the governments of other countries on the development of systems for transporting CO2 across borders (e.g., measuring, reporting, and verifying the amount of CO2 to be transported and stored, and determining the cost of CO2 treatment by receiving country).

### 5.2.4 Zero emissions electricity

Another major issue in the decarbonization of the steel sector is the need to secure zero-emission electricity. As mentioned above, competitive zero-emission electricity will be needed for hydrogen production, and when the ratio of electric furnaces is increased in the future, zero-emission electricity will be needed to supply the electric furnaces. As for the power supply mix, the mix target for 2030 has already been set, and the reference figures 2050 has also been provided. Needless to say, renewable energies such as solar power and wind power will be the main source of zero-emission electricity in the future, but due to the limited renewable energy resources in Japan, it will also be necessary to secure electricity from nuclear power, hydrogen, and ammonia. In particular, although the operating rate of nuclear power has been sluggish since the 2011 earthquake, nuclear is a power source with the volume and supply stability required for industrial power, and thus should be maintained as a key power source for promoting decarbonization in the steelmaking sector.

#### 5.2.5 Financing

The energy transition will require a large amount of money, and the government is expected to facilitate the inflow of money to the decarbonization actions by the steel industry. The Japanese government currently develops a framework to evaluate the various industry's decarbonization roadmap for transition finance. By encouraging and consulting the industry to draw its own roadmap and appeal its decarbonization efforts to the global investors, the government can promote the inflow of so-called ESG (Environmental, Social, and Governance) money to the industry.

#### 5.2.6 Market acceptability of zero-carbon steel

Finally, as a long-term effort, there needs to be a market condition where society and the market players find an appropriate value for a product with low GHG footprint. It requires a considerable amount of money to manufacture steel products in a decarbonized manner although the quality of the steel product itself does not improve by the amount of the incremental cost. Therefore, society and market must be created in such a way that the burden of incremental cost to produce decarbonized steel to be shared across the entire supply chain. The steel industry should not only work to reduce the cost of decarbonizing its own products, but the government also should promote public education, and if necessary, add some kind of regulatory or policy framework to realize the value of decarbonization.

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# 付録３．カーボンニュートラルにおける蓄電池の役割

# The role of batteries towards carbon neutrality:

# How can distributed electricity storage contribute to balancing supply and demand in power markets as well as in power grids?

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# Content

# List of Figures

# List of Tables

# 1 Introduction

Both Japan and Germany recently declared their commitment to reach carbon-neutrality until 2050 and 2045 respectively. To achieve these goals, the expansion of renewable energy sources (RES) as well as their flexibility options is crucial. With the release of the 6th Basic Energy Plan in October 2021, the Japanese government increased its 2030 renewable production aim by more than 50 % (from 22-24 to 36-38 %). The new German coalition aims for 80 % renewable electricity production in 2030, as announced in November 2021.

Photovoltaic (PV) and wind power will play major roles in the design of the future energy system. Both place different demands on the energy system than fossil fuels due to their dependence on weather conditions and associated variability. It can be generally stated that the higher the share of PV and wind power in the electricity mix, the more flexibility options are needed to provide a constant and secure power supply.

Batteries can be deployed to increase the much-needed flexibility of the power system, amongst other flexibility options. They differ in storage capacity and their main purpose, often depending on their ownership. For example, home batteries are well established add-ons to home PV-systems in both Germany and Japan, but up to now they are mainly used for the maximization of self-consumption by private consumers. The same goes for batteries of battery electric vehicles (BEVs), where until now the only rationale for charging (or not-charging) is the consumers' demand. On the other side of the spectrum, large-scale storage systems deployed by energy providers are already used for different market and grid services as their main purpose.

Possible future applications for batteries include the pooling of home storage systems in a virtual power plant, which then provides electricity and storage capacity depending on the needs of the electricity market or grid. High hopes are also placed on the deployment of battery electric vehicles (BEVs). If their (dis-)charging behavior can be controlled in such a way that it is serving the market or grid, electric vehicles might have huge potential as flexibility options. This potential is increasingly researched and tested in Japan and Germany with the growth of annual EV sales in both countries.

Lastly, one has to keep in mind that the use of batteries is finite. After serving in an electric vehicle, batteries usually can be deployed for other, less demanding purposes. But at some point, they have to be recycled. Both Japan and Germany explore new business models for the so-called second-life use and recycling of batteries, which will become increasingly necessary especially with the spread of BEVs.

This study focuses on how distributed electricity storage can contribute to balancing supply and demand in power markets as well as in power grids. It has been structured as following:

- **Chapter 2** outlines the technical and system background on the integration of batteries into the grid. The current and potential uses of batteries for matching supply and demand and stabilizing the grid, as well as their potential for second-life uses and recycling needs are first be explored conceptually. After that, Japanese and German experiences and potentials with market- or system-serving battery functions are highlighted.

- **Chapter 3** starts with a general analysis on business models and regulatory frameworks needed for the further establishment of grid services by batteries. It then showcases novel business pilots and experiences in Japan and Germany, and presents studies on regulatory frameworks in both countries.
- **Chapter 4** conducts a comparison of German and Japanese potentials, business cases and regulatory frameworks.
- **Chapter 5** concludes and deduces future study/research needs on technology, policy intervention and business development.

# 2 Technology assessment

## 2.1 The current and potential uses of batteries for matching supply and demand and stabilizing the grid

Toward the achievement of carbon neutrality, the power generation, the building, and the transportation sector have been working on the program within each sector. There is a new development that technologies and services are converging from more than one segment in a cross-sectoral manner. This is called sector coupling or sector integration.

Some examples of sector integration will be introduced in the following chapters. They will elaborate the conceptual background of battery use for matching supply and demand as well as grid stabilization by investigating current and potential uses of electric vehicles (short EVs) with focus on battery electric vehicles (BEVs), building-integrated, and grid-integrated batteries.

### 2.1.1 Battery Electric Vehicles (BEV)

In the current phase of the mobility transition, passenger cars are estimated to be idle around 95 % of the time. At the same time, users of electric vehicles generally need only 10 % of the hours in a day for charging, which leaves at least 85 % of the time free for potentially providing flexibility services to homeowners or the grid/the market (Hildermeier et al. 2019). As a stationary battery storage installation is expected to boost the share of roof-top solar power that can be used in buildings, many users may wonder whether they can use EVs as quasi building-integrated storage when they do not use EVs for transportation. In addition to such private uses, BEV batteries could also be used for matching supply and demand and stabilizing the grid. In both cases, the flexibility in charging and discharging electricity to or from the batteries must not compromise their primary use: serving as the power source for the BEV to fulfill the users' mobility needs.

The potential use of BEVs for matching supply and demand and stabilizing the grid can be conceptualized by two stages: 1) flexible charging, where the vehicle owner is adapting his charging behavior to meet power market/grid needs and 2) vehicle-to-grid (V2G), where the vehicle is charged and discharged depending on power market/grid needs. In both stages, the charging/discharging is happening while also respecting the user's demand. The two approaches can be even further differentiated according to their scope (see Figure 1).

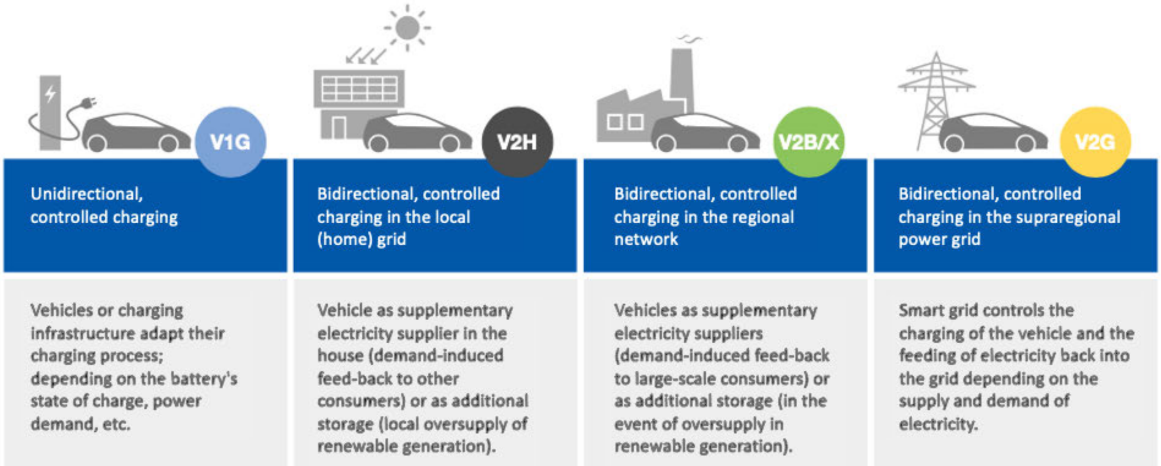



**Figure 1: Concepts for connecting BEVs and the electricity grid. Source: VDE (2021), own translation.**

1) Flexible charging (see V1G in Figure 1): Vehicles or charging infrastructure adapt their charging process, depending on the battery's state of charge, power demand, etc. Previous research highlights the benefits of strategic BEV integration, stating that smart BEV charging can integrate increasing amounts of renewable energy resources, increase utilization of the existing network infrastructure, lower the operating cost of BEVs, and minimize the need for new investment. There is a broad agreement that the grid can cope with integrating the anticipated growth in electric vehicles without issue, provided charging is managed. This means that users are provided with incentives to move their vehicle charging to off-peak hours, thus using the existing grid assets more efficiently (Hildermeier et al. 2019).

2) Vehicle-to-home (V2H): V2H comprises individual solutions for connecting the electrical systems behind the house connection point. The main focus here is on optimizing self-consumption. For example, during electricity production by means of a PV system, additional consumers are activated to absorb the surplus energy. These are primarily consumers that can be switched on at flexible times, such as heat pumps, water heating, or BEVs. The vehicle battery is used as a quasi-stationary intermediate storage unit, into which excess solar power from the roof panels of the house is fed and, if necessary, is also fed back into the house and to the consumers there.

BEVs battery capacities are usually larger than home battery storage capacities, so the use of V2H can store and supply more roof-top PV power. V2H users can also benefit from fast EV charging time by straight DC charging from roof-top PVs to EVs. The biggest obstacle to the use of V2H is the initial cost of the system installation, since a V2H converter costs 4,000-8,000 US $ excluding the installation cost. Many governments provide subsidies as much as half of V2H initial installation cost.

Figure 1 furthermore shows two stages of V2G application:

3) Vehicle-to-business/X (V2B/X): Another form of intelligent vehicle (battery) connection to producers, consumers and distributors of electrical energy would be the Vehicle-to-business coupling. It functions similarly to V2H, except that larger units, i.e., a company, are coupled with several vehicles.

4) Vehicle-to-grid (V2G): The completely flexible use of vehicles as energy storage devices within the framework of V2G applications describes the possibility of controlling vehicles with regard to the public power grid. The goals are the safe and grid-supporting integration of feeding (charging the battery) and feeding back (discharging) into an increasingly volatile energy system (grid service at the distribution grid level), system services for the transmission grid operator according to his specifications/needs and the marketing of the self-generated electricity (VDE 2021). From a technical point of view, all services that can be provided by home storage systems as described in the following chapter, could also be provided by EV batteries with the according technical standard.

In this context, it is important to note that not all BEVs are capable of the above described services today. The technical requirements for bidirectional charging must be considered in all components involved and the communication between them. For example, the two-way power supply with vehicles to buildings requires a V2H compatible EV and V2H converter. Most of the new BEV/PHEV models are V2H compatible, and there are good choices of V2H converters. On the vehicle side, there are two approaches for implementing bidirectionality, which differ according to where the current is converted from DC to AC voltage. This can take place either in the vehicle or in the charging station. Thus, depending on the charging technology, changes to the vehicle side or to the charging facility are necessary for the use of bidirectionality. These changes are associated with additional costs for the charging infrastructure or the vehicle side. In addition, the communication protocol standards currently used in the automotive industry for e.g., in Germany are not yet designed for bidirectional charging (NPM 2020).

### 2.1.2 Building-integrated batteries

In the following section, the residential use of stationary batteries, as well as their use in the commercial and industry sectors (C&I), will be further investigated. Figure 2 shows four stakeholder groups involved in the use of those batteries. The residential, C&I, and the utility group, and the assigned functions will be explored in chapter 2.1.2 and chapter 2.1.3. The first distinction between these groups can be made by looking at the question of ownership: Building-integrated batteries are owned by the building/facility owners and are at a first-place used to optimize their operations and energy costs. They have to be differentiated from batteries located in a building/facility or transformer station and owned and operated by a utility for optimizing its operations. Those would be counted under grid-integrated batteries (see chapter 2.1.3). The off-grid use of batteries will not be the subject of this study, due to its focus on-grid- and system-serving functions.

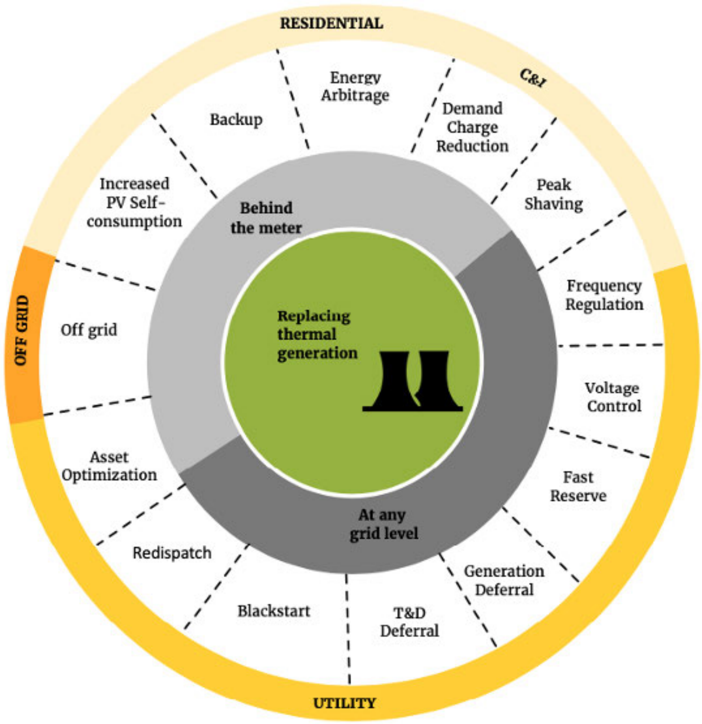



**Figure 2: Batteries can provide up to 14 services to four stakeholder groups. Source: BEE (2016).**

*Grid- and system-serving functions of batteries*

Batteries can contribute to matching supply and demand and stabilizing the grid when used in a grid- and system-serving manner (services under 'Utility' in Figure 2). According to BEE (2015), serving the grid or the system can be conceptualized as follows: Stationary batteries and other battery energy storage systems (BESS) show **grid-serving behavior** when they actively contribute to the stabilization and smooth operation of the electricity grid. The provision of services such as the provision of primary and secondary balancing power, the contribution to voltage maintenance and quality as well as to supply reconstruction are to be located in the area of grid serviceability.

As an extension of grid-serving behavior, a BESS **serves the whole system** when its operational behavior contributes to the overriding goal of making the energy system more flexible. This includes that its use optimally adapts the fluctuating renewable supply to the electricity demand and thus minimizes fluctuations in the residual load. This way, it serves both grid operation and matching supply and demand in the market/the system. The system-serving behavior of BESS requires a high degree of flexibility, communication, and interaction between the various system components.

In contrast to the grid- and system-*serving* behavior, BESS can also be used in a **grid- and system-*compatible*** manner. This means that they only fulfill the minimum requirements that ensure safe and reliable grid operation and the maintenance of the energy supply system.

*The contribution of decentralized batteries for matching supply and demand and stabilizing the grid*

For building-integrated batteries, these functions would come in addition to optimizing their energy bill and their PV self-consumption, in case they operate a PV plant (services under 'Residential' and C&I' in Figure 2). Building-integrated batteries are thus a technical option of Demand Response. For the building owner, such services would be secondary to the primary services expected from the battery, and may also contradict the operation patterns that would optimize its economy or utility, and therefore the necessary incentives for serving their own needs and those of the grid and system will need to be created (cf. chapter 3).

Currently, the main application case for building-integrated batteries is the charging and discharging to **increase the own consumption of self-generated PV power**. For example, in Germany, the electricity price of around 30 Eurocents/kWh can be saved by consuming self-generated power in residential PV systems of less than 10 kW, while selling these to the grid would earn just over 8 Eurocents/kWh (in case of EEG FiT for new PV home systems).

Although direct charging of the residual PV generation after self-consumption is a grid- and system-compatible in principle, it is not necessarily contributing to grid stability. Unregulated self-consumption-optimized operation of home storage systems (HSS) can lead to steep feed-in ramps for individual storage systems, which may pose a challenge to the grid (see Figure 3). Other modes of charging are delayed charging (with preset battery charge level), **peak shaving** (storage of power peaks), and forecast-based charging. They comprise the first aspects of grid-serving behavior. Forecast-based charging combines the different modes of operation and serves both self-consumption and grid operation. Therefore, it represents a basis for a system-serving battery driving mode.

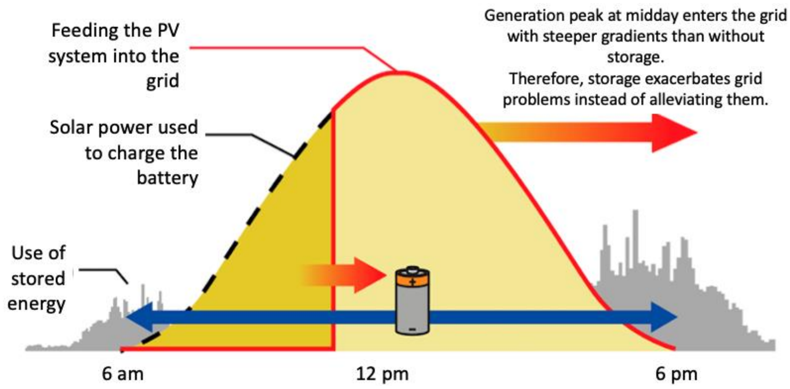



**Figure 3: Unregulated self-consumption-optimized operation of home storage systems. Source: BEE (2020), own translation.**

The service of **energy arbitrage** refers to power being purchased and stored when power prices are low and sold or used when it is higher. Using batteries as an arbitrage application helps to mitigate high electricity prices and to reduce potential low load conditions. Thereby, and within certain limits, batteries can also increase the secured power of fluctuating generators (Table 1: **contribution to secured power**). For example, power can be stored in cases where there is insufficient demand (commonly at night or at the weekends), coincident with large electricity production attributable to growing wind and solar generation capacity. Due to its advantages for both consumers and the grid, energy arbitrage can be considered a system-serving function.

Quite similar, but relevant only for C&I, is the possibility to reduce demand charges with batteries. Demand charges are additional fees that utilities charge non-residential customers for maintaining constant supply of electricity even at demand peaks. Most utility rates specify the maximum power demand a C&I customer is allowed to have in any given interval (usually 15 min.): exceeding the maximum power demand for consecutive months can result in being moved to a different rate with higher demand charges. **Demand charge reduction** refers to the reduction of power draw from the grid during specific time periods in order to reduce the demand charge component of the electricity bills. Lithium-ion batteries (LIBs) are a reliable solution for this purpose. Called upon at key times throughout the day, they are able to manage peak building loads.

Another service of batteries is **backup/uninterruptible power supply (UPS)**: For large industrial customers and datacenters, even the smallest variation in power quality resulting from grid instability can cost millions of euros in lost productivity. Batteries can provide backup power at multiple scales ranging from sub-second-level power quality for industrial operations to household backup when paired with onsite PV generation. Lithium-ion based technologies have evolved to a point where they can now deliver reliable backup power at a price point well below that of diesel generation sets when paired with a renewable generator. In the area of uninterruptible power supply, battery storage systems are now mature and state of the art (see Table 1).

Potential future uses for building-integrated batteries can outlined by an even more system-serving behavior. For example, **frequency regulation** ensures that the frequency of the grid is held within an acceptable tolerance band in order to avoid grid instability. In Germany and Europe this tolerance band lies between 49,8Hz and 50,2Hz. Due to their short reaction times in the millisecond range, battery storage systems are technically ideally suited for the provision of balancing energy up to the minute range (especially instantaneous reserve and primary balancing power). This is already used to some extent in the German balancing market (Ninomiya et al. 2019). In the future electricity system, batteries can increasingly provide balancing power that was previously mainly provided by conventional power plants.

### 2.1.3 Grid-integrated batteries

Grid-integrated batteries are owned by utilities, e.g. grid companies, generators, or suppliers with their generation. They exclusively provide the 'Utility' services in Figure 2.

The current and potential market- and system-serving functions of grid-integrated batteries can be outlined by flexible charging and discharging, respecting power market/grid needs. In its study on decentralized energy storage, the German Renewable Energy Federation (BEE 2015) assessed the technical and economic feasibility of possible applications of battery storage for the integration of renewable energies. Table 1 gives an overview of the results.

**Table 1: Possible applications of battery storage for the integration of renewable energies into the electricity system and assessment of their technical and economic feasibility. Source: according to BEE (2015).**

| Possible applications of battery storage | | | | |
|---|---|---|---|---|
| System services | Security of supply and reconstruction | Contribution to secured power | | |
| | | Uninterruptible power supply | | * |
| | | Black start capability | | |
| | Voltage maintenance and quality | Provision of reactive power | | |
| | | Provision of short circuit power | | |
| | Frequency maintenance through active power control | transient | Instantaneous reserve | ** |
| | | Control and reserve power | Primary control power | |
| | | | Secondary control power | |
| | | | Tertiary control power | |
| | | | Long-term reserve | ** |
| | Grid operation management | Gradient control (ramping) | | |
| | | Network congestion management | | |
| Generation Balancing | Future markets | | | |
| | Spot markets | | | |

Technically feasible and economically viable | Technically feasible, economic viability to be examined | Not economically feasible

* Only Lead-acid battery
** Still to be examined in case of Redox-Flow-Battery

*The contribution of grid-integrated batteries for matching supply and demand, stabilizing the grid*

**Blackstart:** A blackstart-capable power plant is suitable for rebuilding the supply system on an island basis after a supply collapse (blackout) and without external support. BESS can be black-started if designed accordingly and can thus contribute to the reconstruction of supply. With (decentralized) battery storage, wind farms, gas turbines and combined heat and power plants can also be upgraded to black start capability.

**Voltage control**: Grid operators must ensure that the voltage remains within permissible bandwidths and that their operating resources are not overloaded. To achieve this, four measures, in particular, can be taken technically with BESS: Provision of reactive power and reactive power compensation, provision of short-circuit power (fault ride-through), storage, and release of active power for voltage maintenance, and the local stabilization of fluctuating renewable feed-in. The provision of short-circuit power can also be undertaken by building-integrated batteries but would require the pooling of more than one battery.

**Frequency regulation (including fast reserve)**, which was already mentioned in the prior chapter, can also be provided by grid-integrated batteries.

**Grid operation management (e.g. Redispatch and Asset Optimization):** BESS can have a grid-relieving effect by reducing the maximum electricity demand and absorbing steep gradients in the residual load. In the future, batteries can be used in the distribution grid at overloaded grid points in order to alleviate the bottleneck situation and, for example, prevent renewable generators from being shut down. Energy storage can help the grid operator avoid the redispatching process when batteries are deployed downstream of the congested area. So-called “grid boosters” can store power downstream of the congestion point during non-congested periods and dispatching that electricity during periods of congestion. The use of batteries for this purpose may be even more economical in the future than the curtailment in special cases. At present, battery storage does not yet play a significant role here.

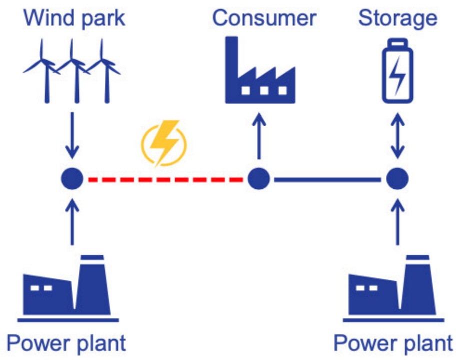



Figure 4: Illustration of a grid congestion point that could be addressed by batteries (so-called “grid boosters”). Source: DENA 2020.

**Generation balancing on spot markets:** The participation of BESS in the electricity markets is technically possible and, with further cost degression, will probably become interesting especially for short-term compensation of the forecast errors of wind and PV feed-in on the intraday spot market of the electricity exchange and in over-the-counter trading. But from today's perspective, the use of BESS on the conventional electricity markets is not yet worthwhile.

In addition to the possible application cases shown in Table 1, BEE (2016) also mentions the following system-serving functions of grid-integrated batteries:

**Transmission and Distribution upgrade deferral (T&D deferral):** Energy storage is deployed in the transmission system to 1) defer the equipment upgrades of T&D due to the increase in power demand or to 2) extend the life of T&D equipment. Energy storage systems provide economical alternatives to developing new infrastructure (substations and feeders), which poses challenges concerning local communities, future demand growth, capital investment, and massive time requirement.

**Power generation deferral:** Batteries can be configured to provide peak demand and entirely avoid utility investments in peak power generation or diesel and gas peak generation units. For peaking purposes, generators are run at 70-80 % of capacity and ramped up or down depending on the grid needs. Putting in storage would enable such plants to be run closer to full capacity, which is a significant cost saving that is critical in countries which have strong growth in electricity demand. Electricity storage is a compelling alternative to ramping up and down existing plants or using expensive and rarely used peaker plants.

## 2.2 The potentials for a 'second life' of BEV batteries

Along with increasing EV deployment, there will be many used EVs and used EV batteries by 2030. In Europe, Japan, and the United States, policymakers and automobile industries are carefully designing the EV battery production capacity. There is a significant interest in securing key materials to manufacture batteries, and used EV batteries recycling is regarded as a promising potential. Before recycling, used EV batteries are also considered for potential re-use as stationary battery storage, such as grid-integrated battery storage (LSS) as well as other uses with fewer loads, such as a battery-powered forklift or a backup battery of street lights.

Despite these interests in second life and recycling of EV batteries, there are few business experiences with used EV batteries due to a short history of actual EV models deployment in the market. Little is known about the actual used EV batteries conditions, and the used EV battery collection process is yet to be developed in many countries.

Many automobiles manufacturers recommend battery replacement when the battery shows degradation as much as less than 70% of the initial capacity after 8 years of use or 160,000 km mileages. In Nissan Leaf case, the new car shows 12-segmented bars in the fully charged condition, and the segment indicator loss means a battery degradation. 11 bars out of 12 is equal to 85% of initial capacity, and 9 bars out of 12 is equal to 73%, which is regarded as the signal of battery replacement. Many users may keep using degraded batteries due to a high replacement cost. The battery replacement cost of Nissan Leaf (40 kWh model) is just over 900,000 JPY.

If EV users keep using the battery too long beyond the recommended limit, such used batteries may not have a second use life, and they will just go to a recycling process. There is also a concerning reality, that many used EVs are exported, sometimes under unauthorized channels. As in the case of Japan, the number of used EVs exported is significantly larger than the industry-wide collected used EV batteries (shown in Figure 5).

Most of the used EV batteries re-use and recycling technologies are already available. Many automobile manufacturers have already conducted demonstration projects, and they understand the challenges in making the re-use/recycling business commercially viable. The first challenge is the cost of remaining health valuations, the process is very time-consuming even with the original battery manufacturers. Then, there is the second challenge that the used battery must be fully discharged and be re-configured for the second application, which is also time-consuming and costly.

Because of these higher costs with the health valuation and the re-configuration, the second use application with smaller capacities, such as a home battery storage or a battery-powered forklift, may not be able to compete with new battery use. In larger capacity applications, such as grid-integrated battery storage, variations of battery module conditions can be acceptable as long as the system-wide performance is being achieved. It is widely acknowledged that the re-use and recycling of used EV batteries may need cooperation with original auto manufacturers/battery manufacturers, because the battery health assessment and the battery operational management are highly confidential and competitive technologies.

Another barrier, which is preventing business development, is a lack of regulation of EV battery re-use and recycling and a lack of information/discussion of EV battery re-use and recycling. That may gradually change, when discussions and interests on EV battery standardization grow during 2022 after European Union proposed legislation on EV batteries in December 2020.

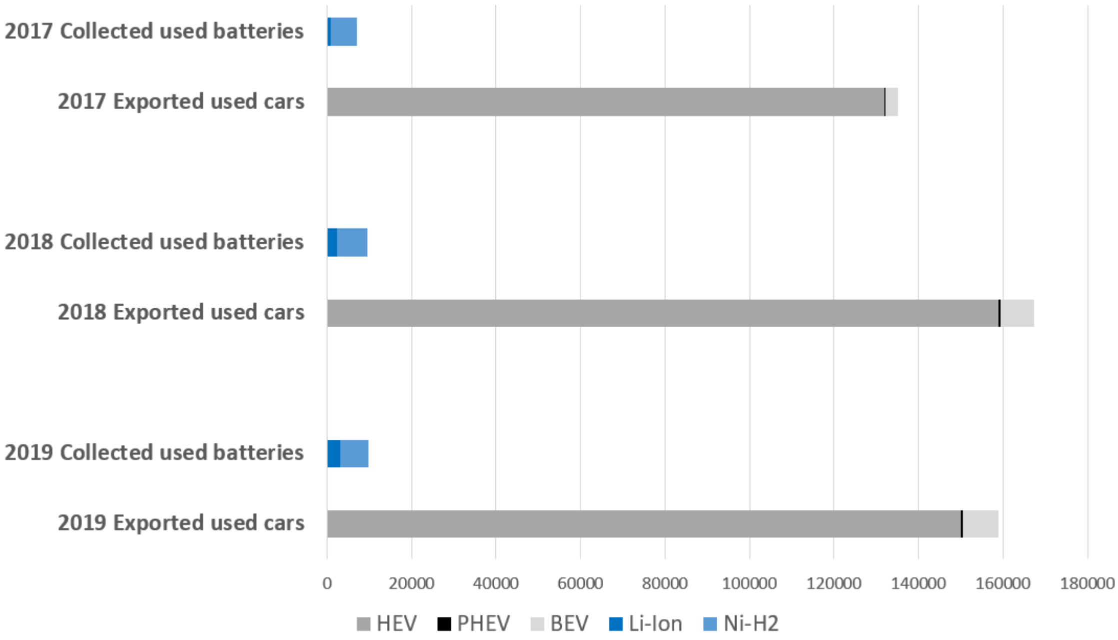



**Figure 5: Comparison of the number of collected used EV batteries and the number of exported EVs in Japan (2017,2018,2019).**

## 2.3 Recycling needs

Large-scale recycling infrastructures will be needed to ensure that the valuable but often toxic materials contained in lithium-ion batteries (LIBs) are not wasted and left for future generations to deal with. Besides the alleviation of toxicity, safety, and contamination risks, further economic and environmental drivers for recycling LIBs are the reduction of the carbon footprint of BEVs, the reduction of BEV costs, the reduction of reliance on mineral extraction, the reduction of reliance on specific suppliers of materials, and the generation of local economic activity (Beaudet et al. 2020).

The recycling of LIBs, which are used for BEVs as well as home storage systems, can be divided into the two stages of components removal and cell recycling. In contrast to portable batteries, LIBs for electric vehicles consist to a large extent (up to approx. 40 % of their weight) of add-on components such as battery casing, cables, battery management systems, various screws, plastic parts, etc. The first step of recycling a LIB is to properly remove it from the passenger cars. Due to the high-voltage batteries, only specially trained electrotechnical personnel may be used for this work. The LIBs can now be transported as hazardous goods to dismantling facilities. Depending on the process, LIBs may be discharged, and components such as casings (steel/plastic/aluminum), cables (copper), battery management systems (printed circuit board scrap) etc. are removed by specially trained personnel using small tools. These components can be fed to existing, conventional recycling plants.

The cell modules can consist of different cell compositions. Most LIBs recently produced are either based on nickel, manganese and cobalt (NMC cells) or nickel cobalt aluminum (NCA cells). The modules are separated and securely packaged and transported to a recycling plant. As with portable LIBs, pyrometallurgical (use of high temperatures), pyrolytic (thermochemical treatment) or mechanical processes are usually used in the next step for the further treatment of cell modules of EVs, depending on the process or company (Öko-Institut 2020, see also Figure 6).

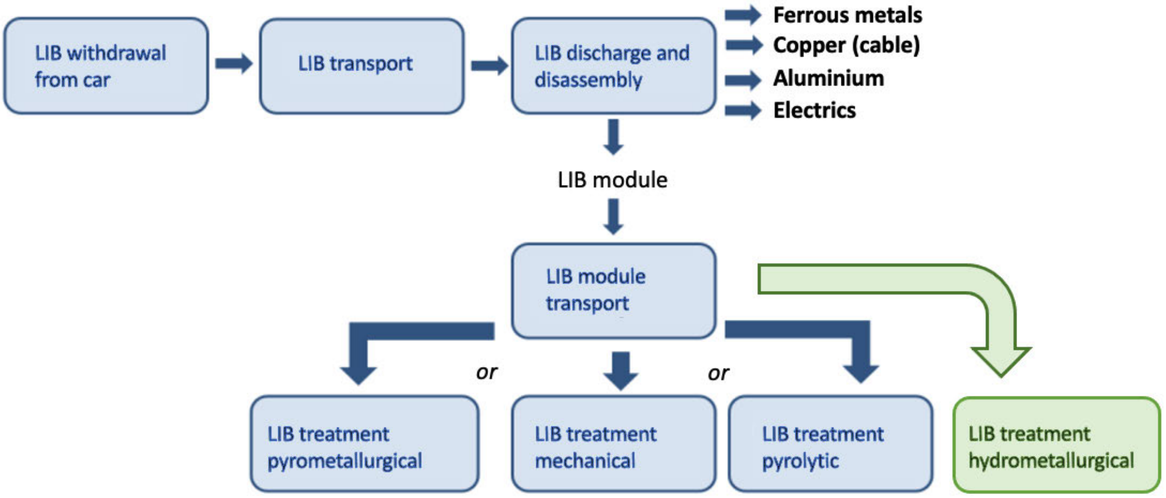



**Figure 6: Scheme of removal, unloading, dismantling and subsequent treatment step of LIBs from electromobility. Source: Öko-Institut 2020, own translation and with modification.**

One of the biggest challenges in the various recycling processes is the control of thermal runaway (TR) and the high fire load of a LIB. Fire incidents are repeatedly reported in connection with LIBs. These are caused by heating or mechanical damage to a cell, internal pressure build-up, a bursting of the cell, its subsequent self-ignition and the combustion of cell electrolytes and plastics. The TR of a lithium-ion cell can lead to particularly rapid and large fire events if there are many lithium-ion cells in a dense room. Therefore, all areas of the recycling industry where LIBs are collected, transported, stored and handled must be organized and technically equipped in such a way, that the TR of a cell can be detected as quickly as possible and countermeasures can be initiated or the extent of damage can be kept as low as possible (Öko-Institut 2020).

## 2.4 Germany: Existing experiences and potentials

This chapter starts with an overview of the development of stationary BESS in Germany as of 2020 and the development of the BEV market. Possible scenarios for 2030 and beyond will be explored. We will then go on presenting existing experiences and potentials in Germany in the field of stationary batteries, EV batteries, and second life/recycling.

Detailed information about the markets for home storage systems (HSS), industrial storage systems (ISS), and large-scale storage systems (LSS) in Germany is provided by Figgener et al. (2021). Concerning the market for HSS, the growth of the last few years continued in 2019. Approximately 60,000 new HSS, with a total battery power of around 250 MW and storage capacity of 490 MWh, were installed in 2019. This adds up to a total of 185,000 HSS, with a power of about 750 MW and a storage capacity of 1,420 MWh by the end of 2019. By May 2020, the new database of the German Federal Network Agency, “MaStR”, showed over 90,000 HSS registrations in total and is growing continuously. The market for HSS is dominated by domestic producers. Three of four HSS sold in 2020 have been produced either by one of the German companies Sonnen, E3/DC, and SENEC or the Chinese company BYD (EUPD Research 2020). The average net storage price for an HSS was estimated to be around 700 Euro per kWh in 2020. Compared to 2017, the price has dropped by more than 20 % (EUPD Research 2020, cited in PV magazine 2021) and is expected to decrease even further due to falling prices for LIBs. Since the beginning of 2013, it has been possible to finance HSS via a promotional loan. The German federal promotional bank (KfW) offered low-interest loans with a repayment subsidy. However, the KfW "Renewable Energy Storage" funding programme was discontinued in 2018. Interested households now have to resort to the programme "Renewable Energies - Standard" – a more general low-interest promotional loan for electricity and heat (KfW 2021).

Figgener et al. (2021) also give some insights into the ISS market, which thus far has mostly been uncharted. Approximately 700 ISS with storage capacities greater than 30 kWh have been registered. The registered ISS added up to a cumulative power of around 27 MW and storage capacity of over 57 MWh by the end of 2019. However, the current state of the ISS database still does not allow for comprehensive estimates of the overall German ISS market.

With respect to the LSS market, which includes mainly grid-integrated batteries, in 2019, only nine new LSS projects came into operation with a battery power of 54 MW and storage capacity of 62 MWh, indicating a strong decline in the market growth. The new and earlier installations add up to a total of 68 LSS in operation, with an accumulated power of 460 MW and a capacity of about 620 MWh. These mainly operate in the market of frequency containment reserve (FCR). The market environment for LSS has become more difficult in recent years. The expansion of battery storage is increasingly leading to a saturation of the market with falling FCR prices as a consequence. For example, while the average price per week for FCR in 2015 was still at 3,650 Euro/MW, this price fell to an average of 1,500 Euro/MW by the first half of 2019 (Tepe et al. 2021).

Although the Federal Government missed its proclaimed aim of one million BEVs in 2020, the number of all-electric cars in operation in Germany has picked up steam over the past decade and recently reached new heights. About 400,000 cars with electric drive systems were newly registered by customers in 2020, compared to 112,000 in the previous year, which results in an overall market share of 12.6 % in 2020 (Roland Berger 2021). The market for BEVs and electromobility, in general, is subject to extremely dynamic development. In 2019, 276,500 BEVs were produced in Europe at 17 locations in eight countries, including six in Germany. According to a study by the Chemnitz Automotive Institute CATI (2020), more than a fourfold increase compared to 2019 can already be expected by 2022. The study forecasts production of 1.2 million BEVs in Europe for 2022, and more than two million units for 2025. In 2020, Germany overtook France as a BEV production location for the first time. According to the study, this development will continue to gain momentum until 2025. The annual production of BEVs in Germany is expected to increase almost eightfold from 2019 to 2022 to around 600,000 vehicles and will rise further to over 1.1 million BEVs by 2025. A good 50 %

of all BEVs produced in Europe could then be produced at German locations. This development is already much faster than that for hybrid vehicles, including plug-in hybrid vehicles.

### 2.4.1 The current and potential uses of batteries for matching supply and demand and stabilizing the grid in Germany

Experiences in Germany in the field of stationary batteries and EV batteries range from established business sectors, which will be shortly described in this chapter, to pilot projects, which will be further explored in chapter 3.2. This chapter also presents general trends and potentials.

Particularly regarding HSS and BEVs, Germany is still gaining experiences in pilot projects, while the typical use is for optimizing PV self-consumption, with the problems shown in Figure 3, and BEVs will just be charged whenever the user needs it.

One exemption is the case of HSS pooling, where there are some well-established ventures on the German market. For example, the producer of battery storage systems SENEC (formerly Deutsche Energieversorgung, DEV) offers a virtual electricity account, with which surplus electricity is “loaded” into the virtual “Senec. Cloud” and can be accessed free of charge in winter (SENEC 2021). Sonnen GmbH’s “Sonnen community” Virtual Power Plan (VPP) uses blockchain to track and bill the mutual exchange of power between the several thousand owners of small PV plants and batteries aggregated in the VPP (see also chapter 3.2 and Ninomiya et al. 2019).

In Germany, utility-scale LSS with an output in the range of several MW and capacities of several MWh are operating for several years. One example is the battery power plant of the municipal utility WEMAG, which was developed in cooperation with the battery system provider Younicos AG. With an output of 5 MW and a capacity of 5 MWh, the battery power plant provides positive and negative FCR. In addition, the system is able to take over transient tasks, such as the provision of short-circuit power, instantaneous reserve, and other services in grid operation management (BEE 2015).

Concerning stationary batteries in general, an annual expansion of around 10 to 30 GWh of storage could be necessary for the EU by 2035, depending on the speed of the expansion of renewable energies (Fraunhofer ISI 2020). In its recently published scenario, the Federation of German Industries (BDI 2021) assumes 21 GW of storage capacities in 2030 in Germany, compared to 10 GW in 2019. 12 GW thereof is supposed to be (not further specified) battery storage. According to the German government's grid development plan (NEP 2019), PV home storage alone could provide up to 10.1 GW of power by 2030.

In its coalition agreement from November 2021, the new German government proclaimed the aim of 15 million BEVs in 2030 and thereby enhanced the prior aim of up to 10 million (Federal Government 2019). Recent scenario studies suppose similar numbers of BEVs in 2030 (for example Agora et al. 2021, BDI 2021). BDI (2021) also expects an average EV battery capacity for passenger cars of 105 kWh in the upcoming years. The total storage capacity of all passenger BEVs in Germany could therefore amount to 1.575 TWh in 2030. In comparison: A study conducted by Prognos et al. (2021) on behalf of the government in November 2021 estimated a gross electricity consumption of 658 TWh in 2030. Of this, around 44 TWh is accounted for by passenger cars, 7 TWh by light commercial vehicles and 17 TWh by heavy commercial vehicles. If the electricity consumption for buses and two-wheelers is also added, the total estimated electricity consumption for electromobility in 2030 will be around 70 TWh (excluding rail transport).

In its "Charging Infrastructure Master Plan", the German government previously had assumed up to 10 million electric vehicles in 2030 (Federal Government 2019). This would correspond to a charging capacity of 10 GW or 12.5 % of the assumed total load in the transmission grid for 2030 (80 GW). If the target of 15 million EVs already in 2030 is achieved, this capacity may increase to 15 GW.

These numbers may also represent an opportunity for flexibility and security of the electricity grid, should a large proportion of (domestic) connections be controllable in 2030 (VDE 2021).

### 2.4.2 The potentials of for a ‘second life’ of BEV batteries in Germany

In the relatively young market of electromobility in Germany, discarded traction batteries have not played a major role so far. This is about to change. According to typical ramp-up scenarios, the resulting capacity from discarded batteries could amount to 50 to 70 GWh annually in 2035. But the question remains open as to how large the proportion of batteries will be that is still powerful enough for further use in secondary applications, for it is still unclear today when and why the end of battery life is typically reached in the vehicle. The warranty conditions of the device manufacturers indicate that a claim for replacement exists when the range of the car drops to 70 to 80 % of the nominal range in less than ten years or 150,000 kilometers driven, for example. However, it is not yet possible to estimate what this means for vehicles over ten years old (which is quite the norm in Germany and the EU). Given the high expected costs of battery replacement and the typical value development of used cars, continued use until actual battery death, which may be well below 70 to 80 % of the nominal range, is quite conceivable, at least for private short-distance journeys. Such a battery would probably no longer meet the requirements of most secondary applications and could only be recycled (Fraunhofer ISI 2020).

Due to higher failure and replacement rates, as well as possibly also a higher fire risks, second-life batteries could disqualify for small and decentralized battery storage systems in particular. This would mean that the home storage market, which is growing strongly in Germany, would not be eligible for these batteries. Larger industrial or grid-serving storage systems, which are still rare today in Germany but could become much more relevant in the future, have a size that would allow the creation of redundant battery capacities and thus the occasional failure of individual battery modules. To be able to pay for this redundancy, second-life batteries would have to be correspondingly cheap (less than 50 % of the cost of a new battery) (ibid.).

Despite these concerns, there are several pilot projects for testing used EV batteries in stationary applications, cf. chapter 3.2.

### 2.4.3 Recycling needs in Germany

Powerful LIBs represent a large share of the market for both electric vehicles and home storage in Germany. In terms of the recycling process, LIBs currently fall under the category of "other batteries" within the EU law, for which a recycling rate of only 50 % of the average weight applies in the European Union (the new regulatory framework on batteries envisages a separate category for EV batteries, see chapter 3.2). Germany reports a collection rate of 48 % for discarded batteries in 2018 and a recycling efficiency for the category of other batteries of 84 %. Fraunhofer ISI (2020) estimated that by ensuring high collection rates and recovering 25-50 % of the lithium from discarded batteries, lithium from battery recycling could meet 10-30 % of the total annual demand by 2050. The EU proposes even higher recycling efficiency targets. According to its new regulatory framework, 70 % of lithium from batteries shall be recovered in 2030 (see chapter 3.2).

The number of discarded batteries ready for recycling in 2030 and beyond depends heavily on the (economic) efficiency of second-life applications for these batteries, and on when these applications reach their end of life. A scenario analysis conducted by Drabik and Rizos (2018) assumes that an average EV battery has a lifespan of 8 years within a vehicle and further 10 years within second-life applications. Based on these assumptions, the study forecasts about 1.1 million batteries reaching their end of life in 2030 within the EU. The authors furthermore calculate the recovery of valuable raw material from those batteries at different recycling efficiency rates. For example, the amount of recovered lithium from EV batteries could amount to 1.2 to 2.4 tonnes per year in 2030, with a recycling rate of 57 % and 94 % respectively. Cobalt (2.9 to 4.1 tonnes), nickel (10.6 to 13.5 tonnes), and aluminum (31.8 to 39.8 tonnes) are expected to have even higher recycling efficiency rates and according to material recovery in 2030.

Little is currently known about the economic viability of recycling LIBs from the automotive sector. Many processes in Germany are only operated on a small scale or are not specifically designed for these batteries. For dismantling, the yield is estimated at 210 to 240 euros per tonne of batteries, with half of the value going to the aluminum contained, a quarter to the steel, and another quarter to the recycling of copper. The actual cell recycling requires significantly more complex processes, for which no cost data is currently available from the industry in Germany. Furthermore, the economic viability of cell recycling depends on the chemical composition of the battery. For example, the metal value contained in lithium iron phosphate-based cells is less than half that of cells containing cobalt and nickel. In addition, the currently decreasing cobalt content in such batteries could make economic processing much more difficult in the future (Fraunhofer ISI 2020, see also chapter 3.1).

## 2.5 Japan: Existing experiences and potentials

### 2.5.1 Current status of grid-integrated large-scale storages deployment

Previously, in the vertically integrated electric power sectors, pumped storage power generations were responsible for large-scale power storage. Pumped storage power generation is reliable engineering with plenty of facilities with historical usage experiences, but there is scarcely a new facility due to the lack of new applicable location, mainly concerns from nature environmental effects. As the energy efficiency of pumped power generation is 70 %, an alternative to a large-scale storage facility is expected to achieve a similar efficiency. In the case of using battery storage, the total efficiency is the multiplication of "charging efficiency" and "discharging efficiency", so both of the battery storage efficiencies are expected to be as much as 80 %, which leaves the choice of available high-efficiency battery technology as LIBs and sodium–sulfur batteries (NaS).

METI (The Ministry of Economy, Trade, and Industry) conducted the technologies verification projects on grid-integrated large-scale battery storages, with the consideration of increasing renewable power generations which may result in instability of grid operations. The 4 years projects started in 2013, with the installation of newly developed battery technologies in power utilities' transformer substations. The projects validated the effectiveness of frequency fluctuation restoration, voltage adjustment, avoidance of renewables power restrictions, and the efficiency of battery storages.

Japan's power grid system is operated by nine regional power-grid operators. Among the nine grids, the Hokkaido Electric Power Company (HEPCO) grid is relatively smaller than those in main-island (Honshu) grids, and HEPCO grid interconnecting capacity with adjacent grid is also small. HEPCO's service area, Hokkaido Island, is suitable for renewable mega-size PV parks, onshore wind parks, and offshore wind farms. HEPCO recently experienced a few cases when frequency fluctuations reached the acceptable limit (0.3 Hz fluctuation from 50 Hz control), resulting in the curtailment of renewable power generations. Since 2015, HEPCO is demanding new mega-solar projects to install battery storage so that the output fluctuation from the PV parks can be controlled within 1 % fluctuation range of the Power Condition System (PCS) output capacity. The mandatory battery storage cost is borne by the mega-PV developer.

**Table 2: Hokkaido Electric Power Co.: Mega-PV projects with mandatory battery storages (2016-)**

| Utility Scale Mega-PV Project | Solar Capacity | Battery Storage | Operation Start |
|---|---|---|---|
| Shin Hidaka Solar Park | 21.0 MW | 9.0 MWh | 2018/5 |
| Loop Nakashibetsu Solar | 31.6 MW | 14.45 MWh | 2019/10 |
| Suzuran Kushiro-cho Solar | 92.2 MW | 25.3 MWh | 2020/2 |
| Softbank Yakumo Solar Park | 106.82 MW | 27.8 MWh | 2020/7 |
| Softbank Tomatouabira Solar Park2 | 64.4 MW | 19.0 MWh | 2020/10 |

HEPCO is also demanding new onshore wind power developers to install a battery storage, but instead of having individual battery storages by project, HEPCO has called a joint battery storage investment at HEPCO's transformer substation (Table 3 HEPCO joint battery development with wind farm projects).

**Table 3: Hokkaido Electric Power Co.: Minami Hayakita Battery Storage cost sharing with wind power projects.**

| Project Stages | Battery Capacity | Wind Power Capacity | Wind Power cost sharing |
|---|---|---|---|
| Stage 1-A (2019/2) | 170 MW- 3 hours | 162 MW | 95 % of battery |
| Stage 1-B (in process) | 780 MW- 4 hours | 438 MW | 90 % of battery |
| Stage 2 (2023/4-, TBC) | 600 MW- 4 hours | 400 MW | TBD |

### 2.5.2 Estimated capacity of grid-integrated large-scale battery storage in 2030

According to the Basic Energy Plan formulated in October 2021 (BEP 2021), renewable is expected to be responsible for as much as 36-38 % of Japan's electricity supply in 2030. In addition to roof-top solar panels in houses and buildings, BEP 2021 expects the installation of mega-PV as much as 16.6 GW to 24.2 GW, 4.4 GW to 8.8 GW onshore wind power, and 1 GW to 5 GW offshore wind power. METI has not started the discussion on the storage planning to absorb the fluctuation of those renewable powers. Dispatchable power generations with coal and natural gas power generations may contribute for now, while BEP 2021 is planning to decrease coal power generations.

This study attempts an estimate of grid-integrated battery development scale with an assumption that a similar requirement with HEPCO's mega-solar and wind power will be implemented at a certain scale across the nation in 2030. This study assumes that 50% of the projects will be required battery storage installation. The study also assumes the required storage capacity from HEPCO cases, a 30 MWh battery per 100 MW PV capacity. With such assumptions, the annual deployment capacity of the grid-integrated large-scale power storage with mega-PV projects will be 277 MWh to 403 MWh (Table 4).

BEP 2021 estimates the potential for wind power generation is as much as 15.2 GW to 23.6 GW until 2030. BEP 2021 does not show the wind power growth path towards 2030, this study assumes the equally deployment of wind power generation towards 2030. METI does not show the wind power projects mapping or a possible requirement of battery storage. This study assumes that 50 % of wind power projects are subjected to the battery storage requirement again and the same capacity requirement as the mega-PV project, 30 MWh battery per 100 MW wind power capacity. With such assumptions, the annual deployment capacity of the grid-integrated large-scale power storage with wind power projects will be 90 MWh to 230 MWh (Table 4).

Combining the mega-PV projects and the wind power projects, installation battery capacity in 2030 will be 3.3 GWh to 5.7 GWh.

**Table 4: Estimation of grid-integrated battery storage deployment in 2030.**

(Assumptions)
- Basic Energy Plan 2021 resource planning is used to estimate mega-solar and wind power deployment.
- Assume a certain ratio of HEPCO battery installation requirement
- Assume 30MWh battery requirement per 100MW mega-solar or wind power capacity.

| | Estimated New Installation Capacity in 2030 (GW) from BEP2021） *A | Battery Requirement Ratio (assumption) | Required battery Capacity per 100MW (assumption) | Estimated battery capacity by 2030 | Annual Battery Installation (2022-2030) (MWh) |
|---|---|---|---|---|---|
| Mega Solar | 16.6～24,2 | 50% | 30MWh | 2.49～3.63 GWh | 277～403 MWh |
| Onshore Wind | 4.4～8.8 | 50% | 30MWh | 0.66～1.32 GWh | 73 ～147 MWh |
| Offshore Wind | 1～5 | 50% | 30MWh | 0.15～0.75 GWh | 17～83 MWh |

| (GW) | 2019 Capacities + Submitted, to be operational | **2030 Capacities BEP2021** | 2030 Capacity Previous BEP |
|---|---|---|---|
| PV | 55.8 + 18.0 | 103.9～117.6 | 64 |
| Rooftop | 14.5 + 0.8 | 28.8～34.9 | 9 |
| Mega-solar | 41.3 + 17.2 | **75.1～82.7** | 55 |
| Onshore Wind | 4.2 + 4.9 | **13.5～17.9** | 9.2 |
| Offshore Wind | 0.01 + 0.7 | **1.7～5.7** | 0.8 |

総合資源エネルギー調査会 省エネルギー・新エネルギー分科会／電力・ガス事業分科会 再生可能エネルギー大量導入・次世代電力ネットワーク小委員会 中間整理（第4次） 2021/10/22
https://www.meti.go.jp/shingikai/enecho/denryoku_gas/saisei_kano/pdf/20211022001_01.pdf

### 2.5.3 Current status of home storage and commercial/industrial storage

The cumulative amount of stationary storage batteries (for residential and commercial industries) introduced in Japan from 2010 to 2019 is 9.6 GWh, which is one of the highest in the world. The Japanese domestic market for stationary storage batteries is largely driven by LIBs used in the residential and the mobile phone tower UPS (Figure 7).

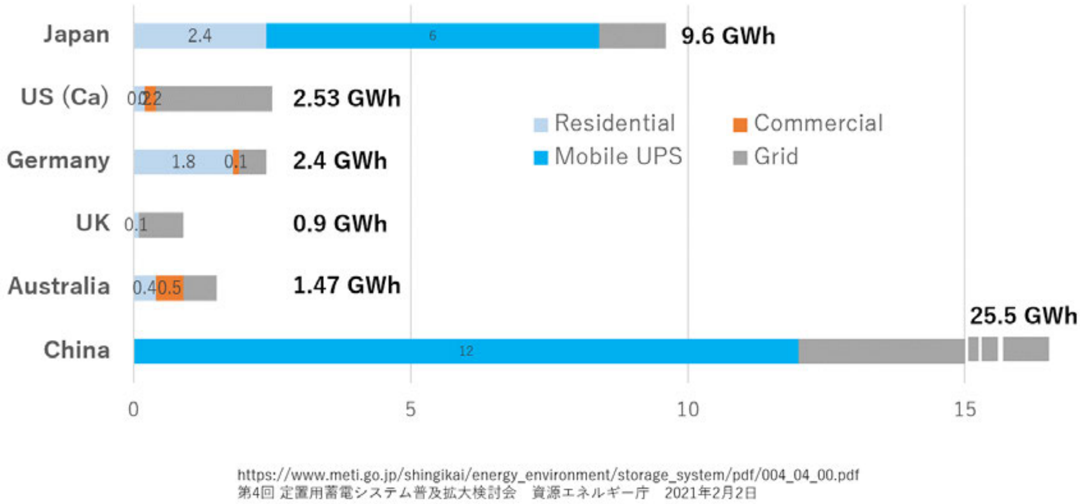



**Figure 7: Cumulative capacities of installed battery storage (2010-2019).**

*Home battery storage: cost reduction and the distribution value-chain*

With continuous works on the cost reduction by METI and the battery value chains, the average unit price per kWh of the battery system (excluding the installation cost) has been reduced by 36 % from 221,000 yen / kWh in 2015 to 140,000 yen / kWh in 2019 (Figure 8). METI has given a strong incentive to decrease the system cost by providing a generous subsidy for the purchase of battery storage, when the unit price is below the target unit price, set each year by METI.

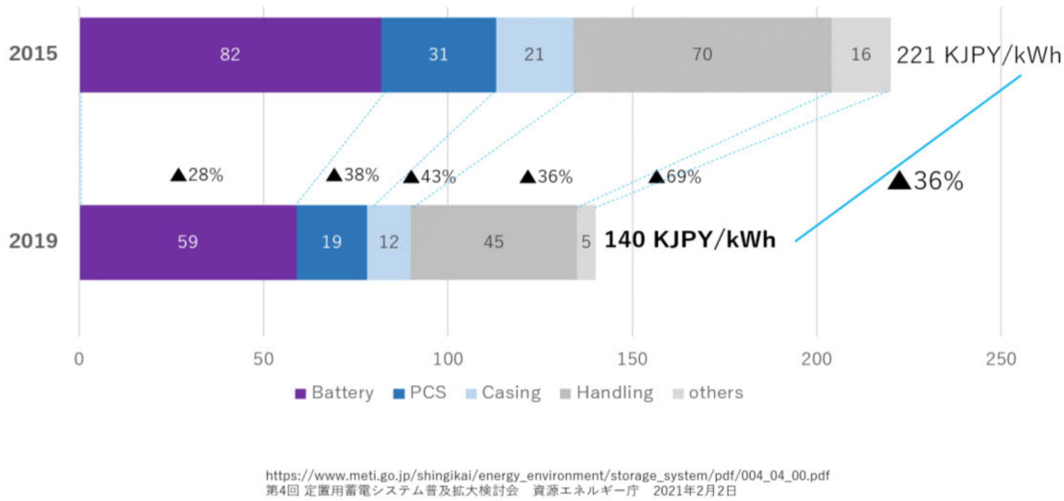


Figure 8: Cost reduction of residential battery storage from 2015 to 2019.

As for the price difference by the battery capacity, the larger the capacity, the lower the system price, but the construction cost varies greatly from project to project, and no difference due to the capacity is observed (Figure 9). The kWh unit price including the construction cost in 2019 was 180,000 yen / kWh.

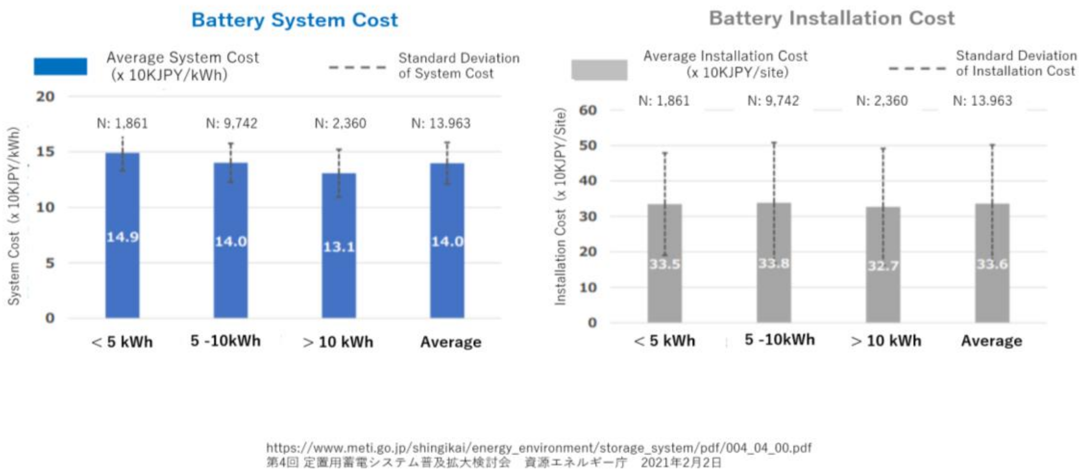



Figure 9: Average residential battery cost differences with battery capacity (2015-2019).

20 % of home storages are installed in new homes and 80 % are installed in existing homes. In the case of new home installation, the battery system will be delivered directly from the electricity storage manufacturer to the housing developers/housebuilders. In the case of an existing home installation, a wholesaler is often placed between the electricity storage manufacturer and the construction company. The wholesaler bears the credit risk of the small and medium-sized construction company, and such a cost is incurred as the distribution cost (Figure 10).

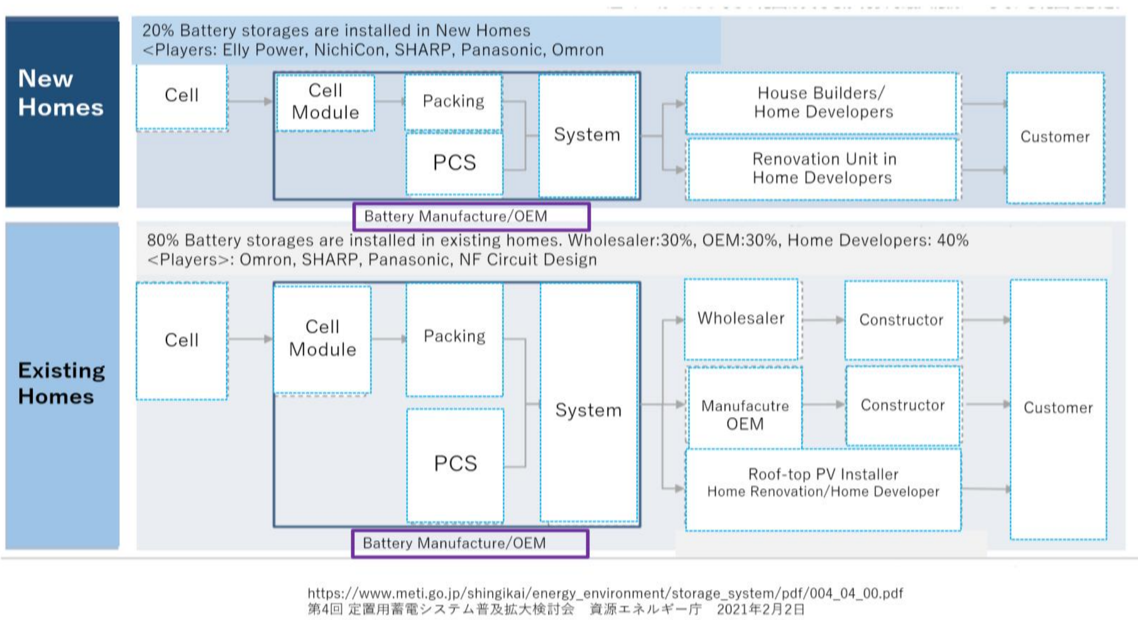



**Figure 10: Residential battery market players and business structures in Japan.**

*Commercial/industrial battery storage: cost reduction and the distribution value-chain*

Similar to a home storage, METI and the battery industry has worked on the cost reduction and the average unit price per kWh of the battery system (excluding installation construction costs) has decreased by 45 %, from 355,000 yen / kWh in 2015 to 195,000 yen / kWh in 2019 (Figure 11). The kWh unit price including the construction cost was 242,000 yen kWh.

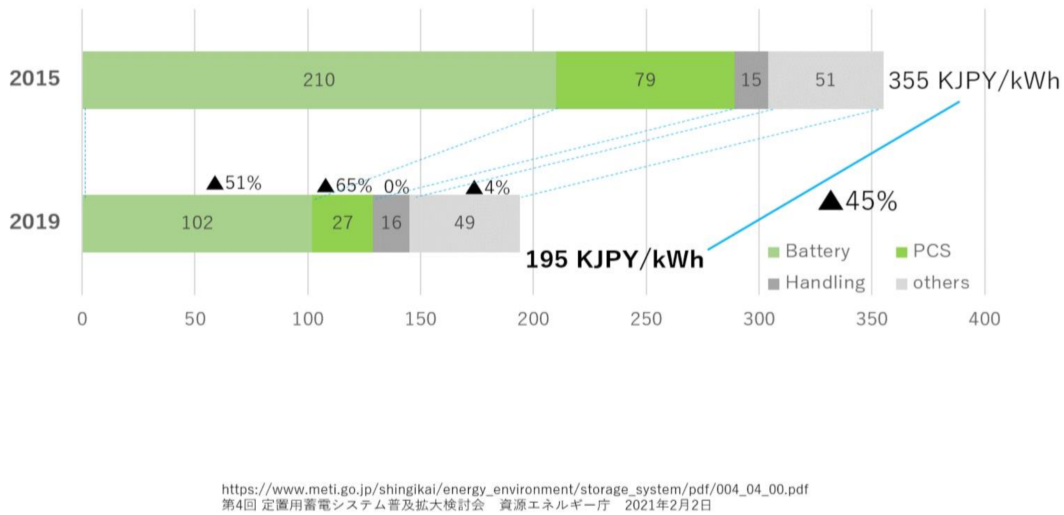



**Figure 11: Cost reduction of commercial/industrial battery storage from 2015 to 2019.**

The distribution channel for an industrial power storage, 100 kWh and more: the system integrators design the entire system, procures the PCS (Power Conditioning System), the battery, and installation. Major system integrators are NIHON GAISHI, Sumitomo Electric, GS Yuasa, Toshiba, LG Chemical, and Sumsung SDI.

The distribution channel for smaller commercial power storage systems, less than 100 kWh: battery manufacturers control system development and sales to users with the use of contractors for installation (Figure 12).

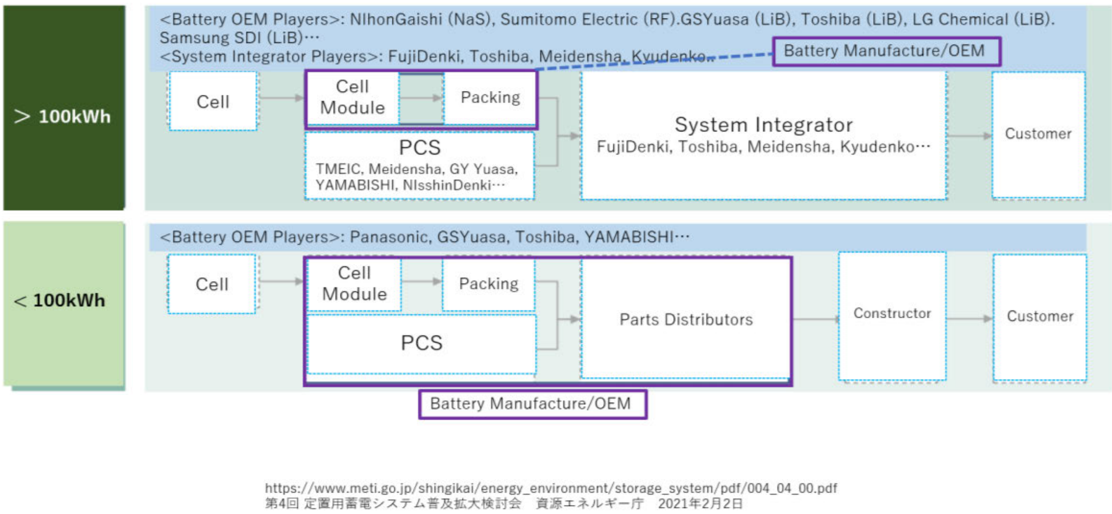



**Figure 12: Commercial/industrial battery market players and business structures in Japan.**

### 2.5.4 Estimated capacity of home storage/commercial and industrial storage in 2030

The current home/commercial-industrial batteries deployment is one of the outcomes of METI's Battery Strategy Project Team in 2012. The project highlighted the steady growth of stationary battery market and xEV battery market and it focused on the battery cost reduction by increasing product shipments. METI re-visited the battery storage strategy after the Japanese Government made announcement on the 2050 carbon neutrality target in October 2020. METI immediately started "The Subcommittee on stationary battery deployment strategy" in November 2020. The Subcommittee worked on the 2030 battery storage strategy, reflecting the new carbon neutral target and the possible new Energy Basic Plan. In February 2021, the Subcommittee published the roadmap of home storage/commercial-industrial storage 2030 targets on cost reduction and the shipments (METI 2021).

*Home stationary battery*

METI's home storage deployment priority and the Subcommittee's roadmap heavily focus on the maximum self-consumption of roof-top PV electricity.

METI and the Ministry of Land, Infrastructures, Transport and Tourism (MLIT) are jointly promoting the newly constructed homes to achieve Net Zero (ZEH: Zero Energy Home), and METI-MLIT expects 60 % of newly constructed single-family homes achieve ZEH standard with roof-top PV by 2030. METI's battery Subcommittee set a target to install home batteries with roof-top PV in both newly constructed single-family homes and existing single-family homes. The maximum use of roof-top PV power is also reflecting the post-FIT (feed-in-tariff), which allowed higher-price purchase by utility scheme of surplus PV generations started in 2012. FIT purchase is gradually expiring from 2021 and METI is focusing on the maximum self-use of roof-top PV electricity.

*Newly constructed single-family home deployment*: METI's Subcommittee set a target of home storage penetration of 40 % in the newly constructed single-family homes in 2030. The current penetration is 9 %, which is equal to 26,000 units. The number of home storage deployments in 2030 will be as much as 84,000 units, 40 % of MLIT's estimate of the newly constructed single-family homes, 210,000 (Figure 13). The total newly built single-family homes with home batteries by 2030 is estimated as much as 550,000 units.

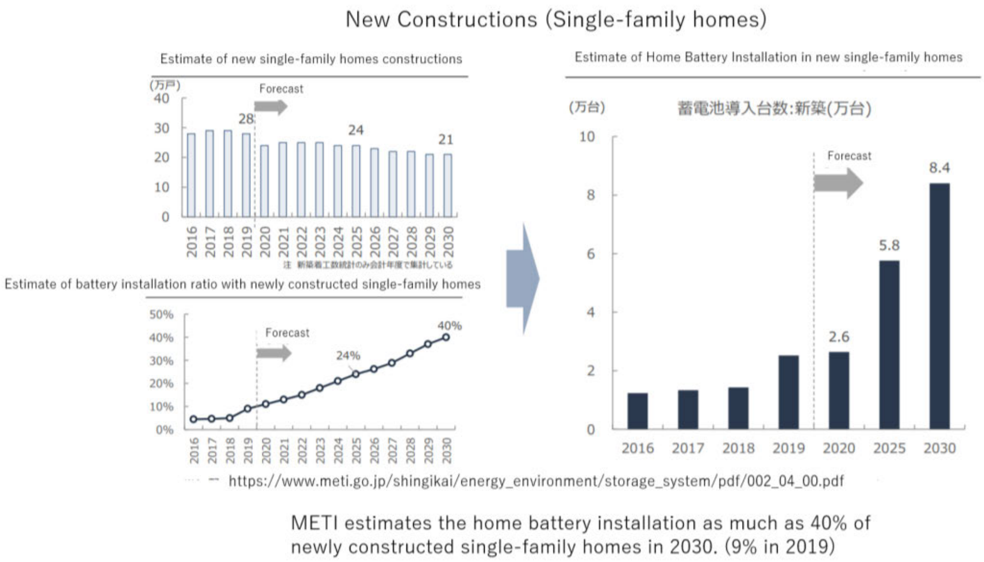



**Figure 13: Home storages 2030 deployment plan, new constructed homes (METI's The Subcommittee on stationary battery deployment strategy).**

*Existing single-family homes deployment*: In existing single-family homes, METI targets (a) a home storage installation to homes already installed roof-top PV, and (b) a home storage installation to homes adding roof-top PV and a home storage. As of 2020, the home battery storage deployment in existing single-family homes is 120,000 units.

(a) The rate of installation of a home storage to roof-top PV-installed homes is currently 1.9 % (as of 2019), and METI expects the rate will increase to 3.2 % as early as 2025.

(b) The rate of installation of a home storage with new roof-top PV installation is currently 1.3 % (as of 2019) and METI expects the rate will increase to 2.7 % as early as 2030.

With these targets, the number of single-family homes with home storage installation in 2030 will be as much as 240,000 units (Figure 14). With this target, the total home storage batteries deployment in existing single-family homes by 2030 is estimated as much as 1.8 million units (METI 2020).

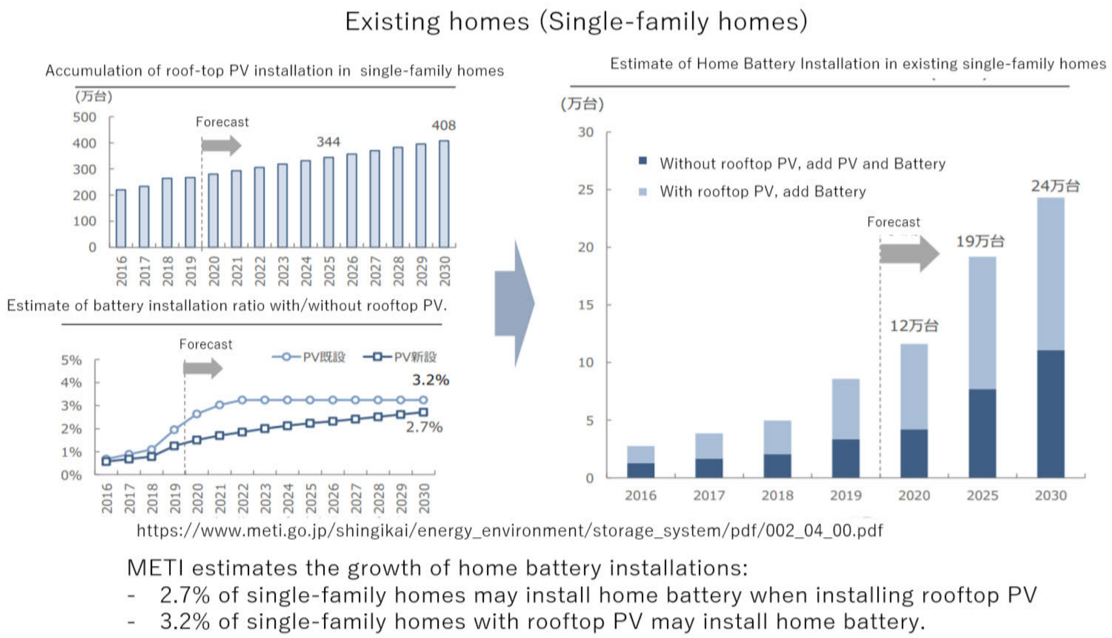



**Figure 14: Home storages 2030 deployment plan, existing homes (METI's The Subcommittee on stationary battery deployment strategy).**

This study assumes that the average capacity of the home storage is 7 kWh, the installed capacity of the home battery storages in 2030 will be 2.41 GWh and the total installed capacity of the home battery storages by 2030 will be 18 GWh.

METI's Subcommittee set a 2030 target reduction of home storage to achieve the above deployment target. The economic benefit of home storage installation is calculated by the self-use of rooftop PV electricity, replacing the purchase of electricity from utilities or power retailers. The target cost of the home storage is 70,000 JPY/kWh including the installation cost, reflecting the home storage investment being recovered by self-use of roof-top PV electricity within 10 years. The 2020 target cost is 187,000 JPY/kWh.

*Commercial/industrial storage deployment*

METI's Subcommittee expects a certain rate of installing commercial/industrial size storages to existing buildings and facilities, targeting four sectors, (1) Local governments and municipal facilities and buildings, (2) Retail Stores, (3) Hospitals, and (4) Manufacturing factories (with 30 or more employees). Table 5 shows the potentials of these buildings and facilities. The storage introduction rate is estimated to be (1) 30 % for local governments and municipals, (2) 10 % for stores, (3) 10 % for hospitals, and (4) 1 % for factories. Estimated average storage capacities are (1) as 15 kWh, (2) as 25 kWh, (3) as 30 kWh, and (4) as 1,000 kWh, respectively. The Subcommittee used (1) the average size of storages received selected municipals subsidies while it used the typical storage product capacities for (2), (3), (4) users (Table 5).

**Table 5: Commercial/industrial storage 2030 deployment plan (METI's The Subcommittee on stationary battery deployment strategy).**

METI's The Committee of Stationary Battery Deployment Strategy estimated the commercial/industrial battery storage deployment potential.
https://www.meti.go.jp/shingikai/energy_environment/storage_system/pdf/003_04_00.pdf (2021/1/19)

| Sectors | Buildings and Facilities | Numbers of Buildings | Ratio of Battery Installation | Battery Capacity | Installation Potentials |
|---|---|---|---|---|---|
| Local Government and Municipals | Municipal Buildings, School, Community Hall, Public Libraries | 230,000 | 30% | 15 kWh | 1.035 GWh |
| Stores | Department Store, Convenient Store Appliance retailors Drug Stores Home Center Supermarket Gas Station | 130,000 | 10% | 25 kWh | 0.325 GWh |
| Hospitals | Clinic and Hospital, Dentist, Veterenarian | 184,000 | 1% | 30 kWh | 0.552 GWh |
| Factories | Food Processing, Manufacturing (textile, pulp, paper, plastic, rubber, leather, metal...) Steel, Non-Steel, Machinery (general, production, office, transport, agricultural...) Electronics Devices and Appliances... | 46,000 | 1% | 1,000 kWh | 0.46 GWh |
| | | | | | **2.372 GWh** |

With these assumptions used by the Subcommittee, the accumulated deployment capacities of commercial and industrial storages by 2030 are 2.372 GWh. Assuming that the annual deployment is constant, the annual deployment capacity of the commercial and industrial storage in 2030 is 0.26 GWh/year.

METI's committee sets a target price reduction of commercial/industrial batteries with the financial benefit from demand-charge savings. The 2030 target price is 50,000 JPY/kWh including the installation cost, reflecting the battery investment being recovered within 8 years. METI's committee previously used a target price per output capacity as KW, but it is replaced by the storage capacity kWh, reflecting the longer duration use.

### 2.5.5 Current status of EV-V2H market

To utilize EVs and PHEVs as home storages, V2H conversion stations are required for both EV/PHEV charging from the grid and EV/PHEV discharging to the grid. There are BEV models capable of V2H in Japan. Hoever, the price is higher than equivalent models with an internal combustion engine, and affordable EV models are yet available as of December 2021 (Table 6).

**Table 6: Available BEVs with V2H function (Japan, December 2021).**

| Make/Model | Battery Capacity | Mileage per Charge (WLTP) | Price (JPY) | Size (L x W x H: mm) | Weight (kg) |
|---|---|---|---|---|---|
| Nissan LEAF / e+X | 62 kWh | 458 km | 4,417,600 | 4,480 x 1,790 x 1,565 | 1,670 |
| Honda e (*1) | | 283 km | 4,510,000 | 3,895 x 1,750 x 1,510 | 1,519 |
| Mazda MX-30EV (*2) | 35.5 kWk | 281 km | 4,510,000 | 4,395 x 1,795 x 1,565 | 1,650 |
| Subaru Solterra (*3) | 71.4 kWh | 530 km | 5,000,000 | 4,690 × 1,860 × 1,650 | 1,930 |
| Peugeot E208 | 50 kWh | 403 km | 4,260,000 | 4,095 x 1,745 x 1,465 | 1,490 |
| Tesla Model 3 Standard Range | 54 kWh | 448 km | 4,290,000 | 4,694 x 1,849 x 1,443 | 1,684 |
| Audi e-tron 50 quattro | | 316 km | 9,330,000 | 4,900 x 1,935 x 1,630 | 2,400 |
| Mercedec EQC | 80 kWh | 400 km | 10,800,000 | 4,770 x 1,885 x 1,625 | 2,470 |
| Tesla Model S Performance | 100 kWh | 590 km | 12,810,000 | 4,979 x 1,964 x 1,445 | 2,241 |

*1: next batch release date unknown, *2: Pre-order, 2022 delivery, *3: Delivery as early as 2022


NISSAN Leaf


HONDA e


Subaru Solterra

Nissan LEAF sales started in 2010, and the cumulative total of 100,000 units was sold in the Japanese market by December 2020 (the worldwide sales are 300,000). Tesla Model 3 may become the next choice in the Japanese BEV market, but Tesla market share is very small in Japan compared with the worldwide Tesla sales exceeding 1.5 million in March 2021.

Hybrid vehicles have been very popular in Japan for more than a decade, but plug-in hybrid models are limited and less popular.

### 2.5.6 Estimated capacity of EV battery storage shipments in 2030

Thousands of reports indicate the massive growth of mobility electrification and the EVs market and there are study reports indicating the use of EVs battery storages in the buildings. METI has high hope of using EV battery storages in buildings and grid balancing, but METI has yet to introduce target numbers of EVs deployment even in the latest BEP 2021. In this study, we used two publicly available EV deployments scenarios (passenger car only) to estimate the size of EV battery storage shipments in 2030.

In April 2019, METI's Next Generation Automotive Study Group used the “2030 next-generation automobile penetration forecast” from the Next Generation Automotive Study Group meeting in April 2010. The forecast predicts 50-70 % of new car sales will become next-generation cars, including hybrid, plug-in hybrid, battery EV, fuel cell EV, and clean diesel. Each type represents the share as much as 30-40 % by hybrid, 20-30 % by battery EV and plug-in hybrid, 3 % by fuel cell, and 5-10 % by clean diesel. In September 2019, The Japan Automotive Manufacturing Association (JAMA) predicts the number of next-generation vehicle penetration in 2030 in METI’s Next Generation Automotive Study Group meeting. While JAMA’s presentation was the forecast of EVs battery disposal and recycling, JAMA used the 2010's Next Generation Automotive Study Group forecast. In this JAMA’s presentation, the numbers of battery vehicles sales in 2030 are 1.45-3.82 million with hybrid and 0.966-1.933 million with battery EV and plug-in hybrid (Figure 15).

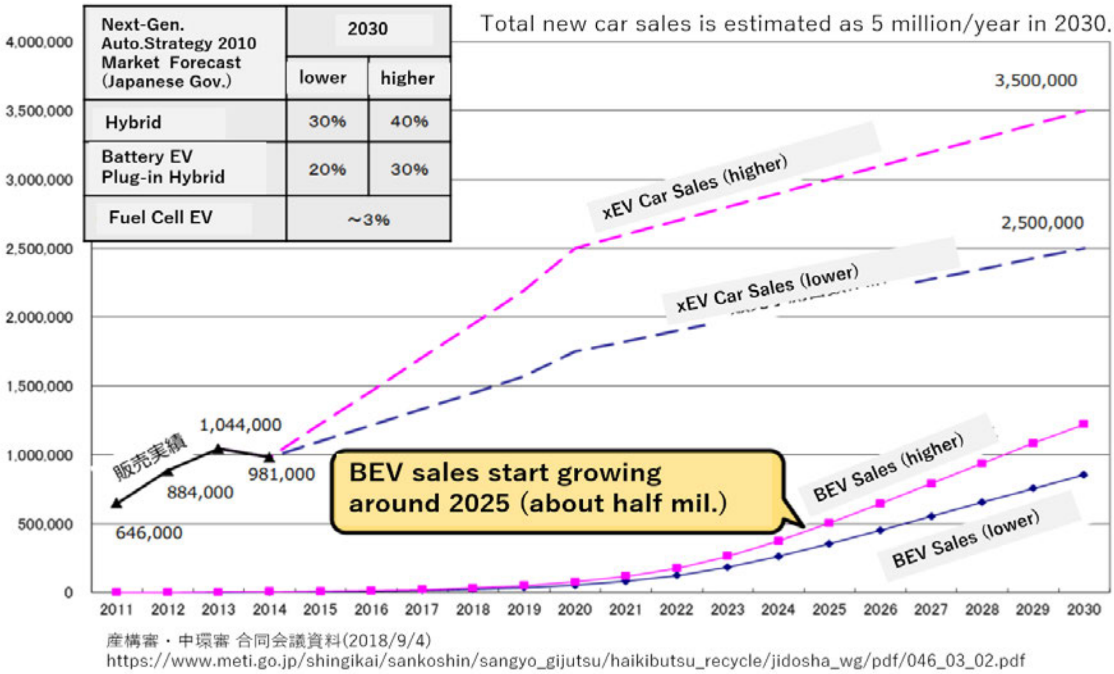



Figure 15: xEV new car sales forecast by Japan Automotive Manufactures association (2019).

In January 2020, Boston Consulting released a research report on “A study on 2030 EVs market penetration, worldwide and Japan market”. For the Japanese market, Boston Consulting forecasts the new generation vehicles penetration exceeds 40 % in 2025 and 55 % in 2030, among the 38 % share will be from Hybrid. This relatively large share reflects the exceptional hybrid cars share in the Japanese market. According to this forecast, the number of hybrid vehicles sales in 2030 is 2.003 million and the number of BEV / PHEV sales is 843,000 (Figure 16).

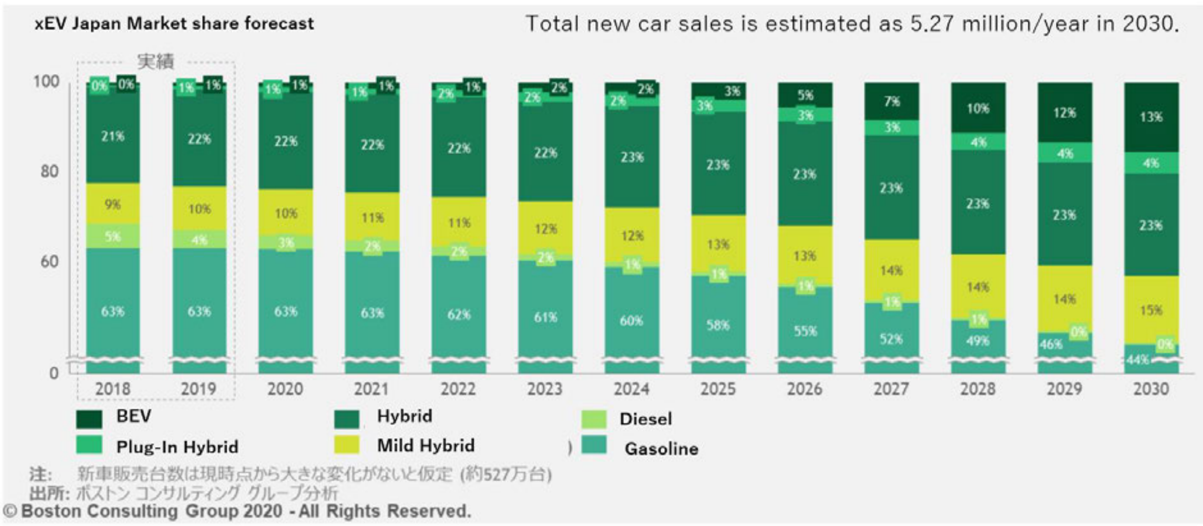


Figure 16: xEV new car sales forecast by Boston Consulting (2020).

The size of EV batteries should differ by manufacturers and models, and this study simplifies the battery capacities as 1 kWh per hybrid vehicle, 12 kWh per plug-in hybrid vehicle, and 55 kWh per Battery EV vehicle. The estimated shipment of EV batteries in 2030 is calculated as 50-75 GWh using JAMA's forecast and 41 GWh using the Boston Consulting forecast.

Hybrid cars battery capacity is relatively very small, as much as 1 kWh or less, the BEV battery shipment quantity is the dominant of EVs battery shipment. Both forecasts could represent rather conservative BEV market penetration, considering recent BEV market growth in China, Europe, and United States. Even this conservative estimate of EVs battery shipment suggests the importance of battery production capacity to meet 50-75 GWh in Japan by 2030, and the battery production investment decision should be made with the BEV market growth forecast.

### 2.5.7 Subsidies of stationary batteries and EV-V2H

There is a subsidy for purchasing EVs and PHEVs, but there is no stand-alone subsidy for stationary storage batteries. From 2019, METI and other agencies are trying to promote battery storage installation to post-FIT (feed-in-tariff) solar panel installed consumers. In 2009, METI started a strong promotion for solar panel installation (residential/commercial), and the solar-generated electricity was sold to utilities at a guaranteed premium price so that the solar panel investment could be recovered within 10 years. These fixed premium purchase arrangements started to become expired after 10 years, starting to show up in 2019. METI is strongly promoting adding battery storage to a solar panel installer so that they can use solar-generated carbon-free electricity as much as possible with a battery.

METI, Ministry of Environment (MOE) and major municipal government (Tokyo Metro included) are providing generous subsidies for adding storage batteries including EV/PHEV.

All of these subsidies demand two conditions, one is a target battery system cost must be below the METI's target price and the other condition is solar panel installation (existing or new installation). Details of subsidies are shown in Table 7.

**Table 7: Subsidies for EVs, Batteries and V2H (Japan, FY2021 as of July).**

| Subsidies Project name | Ministry | Subsidy target | Subsidies Amount | Conditions |
|---|---|---|---|---|
| Clean Energy Vehicles Subsidy | METI | BEV<br>PHEV<br>FCV | 2 KJPY x (Mileage per Charging – 200 km),<br>Limit 600 KJPY per vehicle<br>※ Road Tax/ Vehicle Tax exemption also applicable | - Must to own more than 4 years |
| Pilot projects on Distributed Battery resources aggregation technologies | METI | Residential Battery Storage<br>Com./Ind/ Battery Storage | RESIDENTIAL:<br>40 KJPY/kWh, < 1/3 System Cost<br>COMMERCIAL/INDUSTRIAL:<br>70 KJPY/kWh, < 1/3 System Cost | - Must to have PV<br>- Battery cost must be less than METI Target<br>- Must participate VPP demonstration project |
| Storage Parity demonstration project | MOE | Residential Battery Storage<br>Com./Ind. Battery Storage<br>BEV, PHEV<br>V2H Converter Station<br>Roof Top Solar | RESIDENTIAL Battery:<br>20 KJPY/kW, < 1/5 Install Cost<br>COMMERCIAL/INDUSTRIAL:<br>60 KJPY/kWh, < 1/3 Install Cost<br>BEV/PHEV:<br>20 KJPY x (Battery kWh) /2<br>V2H : 1/2 total cost<br>Roof Top Solar: 40 KJPY/kW, | - Must to have PV<br>- Must not to use FIT or FIP contracts<br>- Battery cost must be less than MOE target (install cost included )<br>RES 165 KJPY/kWh<br>COM 210 KJP/kWh |
| Roof-top PV self consumption promotion Subsidy | Tokyo Metro | Residential Battery Storage | 70 KJPY/kWh, <1/2 System Cost<br>Limit 420 KJPY/Unit | - Must to have PV<br>- Battery cost must be less than 170 KJPY/kWh<br>- Agree to provide usage, charging/discharging data to Tokyo Metro |

# 3 Business cases and regulatory frameworks needed

## 3.1 General analysis on business models and regulatory frameworks

In this section, a general analysis on business models and regulatory frameworks will be conducted. The cases are grouped into three subchapters, due to overlapping challenges and opportunities for businesses and common regulatory framework needs: 1) the case of BEVs, 2) the case of building- and grid-integrated batteries and 3) using BEV batteries in building- or grid-integrated larger stacks, other reuses, and recycling.

### 3.1.1 The case of Battery Electric Vehicles (BEV)

This chapter provides first indicators for business models and framework conditions needed to promote grid-serving charging and discharging behavior of BEVs. Hildemeier et al (2019) conducted a qualitative review of policies for EV grid integration in the EU and U.S. markets. They identified three measures for ensuring EVs are integrated beneficially into the grid, which are: 1) cost-reflective pricing, 2) smart technology and 3) smart infrastructure.

**Cost-reflective pricing** leverages the fluctuations in retail energy and network prices over the course of the day and night to encourage consumers to change how and when they charge their vehicles. An effective program will motivate consumers to change their charging behavior in a way that both lowers their costs and reduces power system costs. The current pricing models range from the simplest, time-of-use tariffs, to the most complex, real-time pricing. With time-of-use pricing, the utility sets different prices for different blocks of time. Real-time pricing, by contrast, changes according to the actual situation on the power grid over set intervals and thus requires smart metering. Table 8 gives examples of business models and experiences with the different pricing models in the context of BEV charging:

Table 8: Examples of time-varing rate design. Source: Hildermeier et al. (2019).

| Tariff Design | Main Features | Prerequisites | User Experience |
|---|---|---|---|
| **Two-period time-of-use tariff for energy (Spain)** | 80% discount for EV drivers charging during pre-defined night hours, at 0.03 €/kWh, compared to the day charge of around 0.16 €/kWh. | Simple binary meter. | A Nissan Leaf owner will save approximately 167 euros per year by charging the EV at the night tariff instead of the standard rate. |
| **Octopus Agile (real-time pricing) (UK)** | Tied to half-hourly day-ahead market, promotes renewable energy use and flexibility. | Smart meter, phone app, active participation of customers. | 150 euros per year saved compared to standard tariff. Energy consumption shifted to low-demand hours. |
| **Radius (Denmark)** | Time-of-use network tariff with a surcharge for winter peak hours (5–8 pm) of 0.9 €/kWh, compared to standard rate of 0.35 €/kWh. | None, standard rate applicable to customers connected to low-voltage (households) and medium-voltage grid (commercial). | - |

**Smart technology** is a critical resource for capturing the flexibility EVs can provide, especially when used in conjunction with smart pricing. Charging processes can even be automated if price and other data can be communicated. This feature is generally found only in more advanced programs.

The goal is to enable consumers to make choices to reduce their bills without needing to constantly pay attention to the relevant technology. The following Table 9 provides examples of business models and experiences with different smart technologies in the context of BEV charging:

**Table 9: Examples of smart technology development. Source: Hildermeier et al. (2019).**

| Technology | Main Features | Level of Consumer Intervention Required |
|---|---|---|
| **Green Mountain Power (Vermont, U.S.)** | Technology and pricing package; charging is controlled by utility and shifted to off-peak hours, includes an opt-out choice. | None. Utility supplies a seven-kilowatt charger free of charge to consumers who buy a new EV, and for a $10 monthly payment to consumers who already own one. The EV owner indicates when the vehicle is available. |
| **Jedlix (NL)** | Application assesses optimal charging profile, including grid capacity, sustainable energy availability, and energy prices, shifts charging to preferential hours. | Very low. Consumer only communicates travel times. |
| **Maxem (NL)** | Wall box/ application to integrate EV charging station, along with any self-generation (e.g., solar photovoltaic), and other uses and appliances (e.g., electrical heating) into a smart home or office building. | None to very low. Application monitors the electricity draw and feed-in for the different applications and implements smart EV charging to ensure safety (e.g., decreases EV charging if the home's demand is greater than its own production and network connection). |
| **MyEnergi (UK)** | Smart meter paired with application recognizes fuel source (for example, domestically produced solar energy) and directs it to EV charging. | Very low. User has option to manually determine charging time and mode. |

**Smart infrastructure** refers to the strategic siting of EV charging infrastructure. More precisely, if the public or private infrastructure is carefully planned, it can serve mobility demands, take advantage of existing grid infrastructure and capacity, and provide balancing services. This powerful combination can substantially reduce the cost of integrating electric vehicles into the power system. The higher objective of this strategy is also to steer the time and location of EV charging to best serve consumers and the grid. The following Table 10 shows examples for smart infrastructure in the context of BEV charging.

**Table 10: Examples for smart infrastructure deployment. Source: Hildermeier et al. (2019).**

| Infrastructure Solution | Main Features | Advantage for Grid Integration |
|---|---|---|
| **Public park-and-charge programme (UK)** | Convert street infrastructure such as light poles into 3–5 kW charging outlets. | Uses existing electrified infrastructure, reduces cost of installation from 8000 to 1000 pounds sterling, encourages off-peak use for parked cars, additional efficiency gain through shared infrastructure. |
| **Study: public fast charging points along existing grid (San Francisco, U.S., and Ottawa, Canada)** | Utility mapping tool identified more than 14,000 locations where fast charging points could be installed to provide every EV driver with a fast charger within a one-mile (1.6 km) radius. Identifies upgrade costs. | Joint energy and transport planning, use of existing infrastructure. |
| **Transmission system operator mapping tool for highway fast charging stations (UK)** | UK's transmission system operator, National Grid, studied 50 optimal locations for fast chargers (up to 350 kW) along highways, allowing 90% of UK | Estimated cost 1 billion pounds, also avoids cost of building new infrastructure by linking these locations to the high-voltage grid. |

| | | |
|---|---|---|
| | motorists to reach a location within 50 miles. | |
| **Battery-assisted charging for cars (Greenlots/Hawaii, U.S.); for ferries (Ampera, Electric Ferry, Norway)** | Hawaii: battery-assisted fast charging infrastructure was built to avoid a more expensive connection to the grid; battery-electric ferry offers "fast charge" for ships ashore and slower charging when the ferry is not plugged in. | |

Concerning vehicle-to-grid (V2G) applications, there is still a predominate uncertainty weather the bi-directional use of EV batteries is economically efficient for all parties. A meta-study conducted on behalf of the two German electricity and energy associations VDE and BDEW reviewed study results on the possibility of V2G system services (FGH 2018). It concludes that competing storage technologies (for e.g., pumped or compressed air storage) are more cost-effective for the provision of system services, so that the economic viability of vehicle-to-grid is not considered to be given so far. Should it nevertheless be possible to develop a business case for the provision of balancing power, a pooling of EVs similar to the pooling of HSS would probably be necessary to enable participation in the balancing power market.

### 3.1.2 The case of building- and grid-integrated batteries

There are various business models through which HSS, ISS and LSS can be used for grid services. According to ADB (2018), these business models range from service-contracting without owning the storage system to outright purchase of the stationary battery. The needs and preference of the service user will determine the specific option to be chosen, which will also depend on the regulatory framework. Table 11 is summarizing the different ownership models for building- and grid-integrated batteries. Batteries serving at the wholesale and substation level can be owned by utilities, independent power producers (IPPs), suppliers/vendors or energy service companies (ESCOs). Also, contracts with IPPs and load-serving entities for grid-supporting services are possible. Building-integrated batteries at the end-use customer can be owned by the customer, ESCOs, IPPs and utilities/load-serving entities (LSEs) and they can be part of utility programs.

**Table 11: Energy storage ownership models. Source: ADB (2018).**

| Wholesale | Substation | End-Use Customer |
|---|---|---|
| Utility-owned | Utility-owned<br>- Grid asset<br>- Smart-grid asset | Consumer-owned |
| IPP-owned | IPP-owned | ESCO (with aggregator)-owned |
| Supplier-/Vendor-owned | ESCO-owned | IPP-owned |
| | IPP/LSE contract for grid support services | Utility (LSE)-owned |
| | | Part of utility program |

ESCO = energy service company, IPP = independent power producer, LSE = load-serving entity

Third-party ownership contracts generally include the following key terms:

- The off-taker holds the dispatch rights for charging and discharging the energy storage system.

- The seller earns a fixed capacity payment for each kW/month and a variable payment for operation and maintenance per MWh delivered.
- In return for the capacity payment, the seller provides assurance of a specified degree of availability of the plant.
- The seller provides an efficiency guarantee.

The economic viability of BESS projects depends on the cost of storage, network reinforcement cost and commercial services enabled by energy market design, as well as the availability of smart technologies and software. From these factors, policy developments needed to further promote stationary battery projects can be derived, which can roughly be described by removing barriers and creating a favorable investment and operation environment (see Table 12, last line). In addition, for BEES projects at the end-use consumer level, **cost-reflective pricing** is as important as for flexible BEV charging.

**Table 12: Key factors affecting the viability of BESS projects. Source: ADB (2018).**

| Factor | Impact on Project Viability |
|---|---|
| **Cost of storage** | Battery costs, while falling, are still the most significant driver of project viability. Costs depend on the MW/MWh ratio of the battery. The terminal value at the end of the project's economic life also has a bearing, with a higher terminal value improving project economics. |
| **Network reinforcement cost** | Higher conventional network reinforcement costs increase the value of deploying storage as an alternative, improving project economics (and vice versa) for DSOs directly and for third-party projects with a contract for peak shaving with a DSO. |
| **Commercial services / energy market design** | Increased access to and higher value from the provision of commercial services (for example, ancillary service markets, the wholesale market, the capacity market) increase project revenue streams, improving project economics (and vice versa). It is generally accepted that value streams will need to be stacked to increase the economic viability of BESS projects. |
| **Policy developments** | Removing barriers to storage or creating a more favourable environment for investment and operation enhances the realizable value of a project, improving project economics (and vice versa). |

### 3.1.3 Using BEV batteries in buildings or grid-integrated larger stacks, other re-uses, and recycling

Second use of EV batteries is often seen as an opportunity to delay disposal and recycling as well as an opportunity to generate value out of existing resources. But despite the potential of a 'second life' to be a good fit for several applications that are less demanding than an EV, there is currently no market for second-life batteries. Partly, that is because EV sales have been low until recently. A study conducted by Olssen et al. (2018) also found out that investors still hesitate when it comes to batteries' second life because of major uncertainties about battery composition, cost and its performance in different applications.

However, due to uncertainty about future battery volumes and chemistries, investments in recycling processes are not easily accomplished either. EV LIBs are made by many different manufacturers with many different constructions, which include variations in number and type of cell, physical shape and chemistry. LIBs are usually not labelled with their specific chemistry, so neither third-party battery refurbishers nor recycling actors know which kind of LIBs they receive. In addition, each LIB has a tailored management system (BMS) which regulates critical functions of the battery. This means that large costs are often associated with repurposing. Standardization of diagnostics, health monitoring, packing and labeling could simplify the process, but as common standards could interfere with competition between manufacturers this is a sensitive issue. Transport is another troublesome issue, as used LIBs can be considered to be hazardous waste. That means that transport is costly and highly regulated. Some logistics firms will not transport used LIBs, and air freight is not allowed at all. This is of course a problem for recycling as well as for second life.

Based on the above analysis, Olssen et al. (2018) describe four business concepts for the (future) reuse and recycling of BEV batteries. The “**Linear model: currently practiced recycling**” is the closest to the situation as it is today. The original equipment manufacturer (OEM) uses customized modules and packs for the first use in their cars. The close partnerships that the OEM has with dismantlers allows to collect almost all batteries for recycling after first use. Removal of the batteries from the EVs and unpacking (i.e., opening up the battery packs to separate the modules from other components and packing materials) can be performed by workshops certified by the OEM or by the dismantlers, before transport to recycling actors which perform recycling processes.

The “**Optimized recycling: state of the art recycling**” would require investments from the recycling actors in scalable and automated recycling processes. With close collaboration between the OEM and the recycling company, the recycling actor could then collect removed batteries from the cars after their first use, from workshops or dismantlers. In this scenario the recycling company performs both unpacking and recycling in an automated process which allows handling of large volumes of batteries with different designs.

The third model is the “**Circular model I: repair and refurbishing for second use in vehicle in the same or a new market + state of the art recycling**”: After the first use in a vehicle, diagnostics are performed by workshops or dismantlers, to decide whether the batteries are in good condition and have capacity for reuse in a car. If that is the case, the OEM-certified workshop performs refurbishment and repair of the battery which is then placed in a car in the same or a new market (e.g., with less intensive driving demands).

The "**Circular model II: repackaging and second life in a different application + state of the art recycling**" would require the highest degree of collaboration among the different stakeholders in the value network, including the OEM, dismantlers, recycling actors and second-life actors. After the first use in a vehicle, an early diagnosis is performed by dismantlers to decide whether the batteries have capacity for reuse in a car, whether they are fit for refurbishment, repacking and transportation for use in second-life applications (e.g., home electricity storage), or if they should be recycled. Based on this decision, the battery may enter different flows. For a transition to a second life, the battery needs to be repacked and the BMS needs to be adjusted or even replaced, which are additional activities that need to be incorporated in the business model.

Concerning the framework conditions needed, Beaudet et al. (2020) identify three priorities for policymakers aiming at accelerating investments in battery reuse and recycling: 1. funding for Research and Development (R&D), 2. funding for pilot projects, and 3. market-pull measures to aid in establishing a favorable investment environment for LIB collection and recycling.

### 3.1.4 “Energy as a Service (EaaS)”

There is a growing expectation in the new business which provide V2H/V2B "As A Service". "As A Service" business cases are emerging in roof-top PVs and building energy efficiency: A service provider pays equipment/systems, installation, maintenances, and operations with monthly fees, and a few precedent players are providing V2H as a service. Both German and Japanese policies are going to promote ZEH (Zero Energy Home) standard houses and ZEB (Zero Energy Building) standard buildings, so we may expect more business cases in "Energy as a Service (EaaS)" with roof-top PVs and V2Hs/V2Bs.

There are business cases that provide roof-top PVs and home/commercial/industrial battery storage as an optional service of electricity supply, in Germany, Australia, the UK, and the United States. Service providers install roof-top PVs and home/commercial battery storage and they supply electricity by optimum use of PVs and batteries. In such a service, PVs and battery storage models are limited to the operators' specification and a service company needs additional monitoring and control system installation.

We can foresee that such EaaS providers may expand their menus in V2H/V2B service, but we need to understand that there are notable challenges in V2H/V2B-as-a-service compared with a home/commercial battery storage-as-a-service. The first challenge is the forecast of transportation use. While a home/commercial battery's primary function is to supply power to a building, the primary function of EVs is in transportation use and transportation use will largely vary by days, hours, and users. The second challenge is to understand EV battery management when EV battery charging/discharging with sustaining a battery’s life is in an EV manufacturer's technical competence domain.

EaaS providers control lightings/air conditioning as well as battery storage to balance the power demand and supply. The demand-supply is not necessarily balanced in a single home/building, the balance is usually managed in a balancing block with thousands of supply homes/buildings aggregation. Service providers use aggregated distributed resources as if they operate a utility-scale dispatch power generation to achieve the grid-scale demand-supply balancing known as a "Virtual Power Plant (VPP)" (see also Ninomiya et al. 2019). When using VPPs more competitively, service providers can expect additional revenues through providing capacities/reserves to an electricity grid operator. With increasing distributed resources and available digital technologies, the energy industry is expecting business growth in VPPs. In Japan, a series of VPP technologies evaluation projects have been carried out since 2015 and we see a precedent business case in Germany and UK by Sonnen.

The VPP business is preceded by examples of using demand response such as lighting/air conditioning controls, self-power generations, and home/commercial/industrial battery storage. With the deployment of EVs, more experiences with V2H/V2B with data analysis may help a VPP business to expand V2B/V2H resources.

## 3.2 Germany

The following section will explore pilot projects on the grid-serving integration of BEV and stationary batteries as well as the reuse and recycling of BEV batteries in Germany. It will furthermore discuss necessary framework conditions for the further promotion of those ventures and other businesses in the field of battery deployment and use, reuse and recycling.

### 3.2.1 Existing business pilots and experiences

*Using BEV batteries for grid services*

A number of pilot projects examine the integration of new types of technical units such as BEVs into VPPs and the grid. For example, TSO Amprion already prequalified a Nissan Leaf electric car for FCR (Ninomiya et al. 2019). Together with the German TSO TenneT and the technology company The Mobility House, Nissan has also completed a major vehicle-to-grid (V2G) pilot project in 2020. As a part of a **SINTEG showcase project** funded by the German Federal Ministry for Economic Affairs and Energy, the project investigated the potential of EV batteries to store locally produced electricity and feed it back into the grid to stabilize the power grid while increasing the use of renewable energy.

Within the project, the wind power available in the north of Germany was used by regional Nissan LEAF EVs, while electricity from fully PV-charged batteries in the south was fed back into the grid at the same time. Thereby, the use of renewable energy was increased and the need for wind power to be curtailed in the north was avoided. At the same time, the mobility and charging requirements of vehicle users were taken into account. These intelligent redistribution measures were controlled by software from The Mobility House, the ChargePilot intelligent charging and energy management system, which follows specifications from the TSO TenneT (TenneT 2020). This ChargePilot software was first used to enable flexible charging, but can also be used for vehicle-to-grid electricity feed-back. The project can serve as one example for the use of smart technology (see chapter 3.1.).

Another example is the **"i-rEzEPT" project**. It aims to demonstrate, by means of a field test, that electric mobility can be independently coupled with both electricity grids and real estate. Electromobility is to serve as a buffer storage for the respective building and also be available for the balancing energy market as primary balancing power. As part of the field test, Nissan has provided 13 PV system owners from all over Germany with a Nissan LEAF and a matching charging station. i-rEzEPT was launched by Nissan together with Bosch.IO and the Fraunhofer Institutes for Industrial Engineering (IAO) and for Manufacturing Technology and Advanced Materials (IFAM). The project is being funded by the Federal Ministry of Transport and Digital Infrastructure and is running until October 2021 (NOW 2021).

*Using stationary batteries for grid services*

The electricity provider **Sonnen** (see also chapter 2.4) recently developed a business model for PV plants that are excluded from EEG subsidy. In Germany, PV plants are supported for 20 years with fixed feed-in tariffs. After that period, they have to participate in the regular market, which is often costly, especially for small plants. Sonnen offers owners of EEG-excluded PV systems an economically attractive option for continued operation. The household does not have to take care of a direct marketer or technical and other requirements. Electricity that cannot be consumed by the household itself or by the so-called sonnenCommunity is marketed by Sonnen directly on the wholesale market at the currently valid price. Producers receive a profit share for participating in the VPP. In addition, each household receives an individual free electricity quantity from Sonnen, which can cover a large part of the annual electricity demand (Sonnen 2020).

In Germany, LSS have recently begun to be used to ensure black start capability. The proof of concept was successfully completed during an experiment in Schwerin in 2017. In this experiment, a BESS was used to start up a gas turbine and to gradually restore grid operation. In April 2019, the **Bordesholm energy storage** became operational. While its primary purpose is to provide FCR, it is also used to provide black start capability on a regular basis as well as islanding capability. The project successfully tested the continued operation of (parts of) the grid in case of outage of the main electricity source utilizing distributed electricity generation (DENA 2020).

The grid booster concept (see chapter 2.1, Figure 4) requires technologies which are not fully developed and available yet. However, TSOs in Germany are planning to develop and deploy grid boosters. For example, Transnet BW – a South German TSO – is planning a **grid booster facility** with a capacity of 250 MW. Two further German TSOs, Amprion and TenneT, are also planning grid boosters (DENA 2020).

*BEV batteries reuse and recycling*

Different projects explore the possibility of the second life of BEV batteries. In 2018, a joint venture between Daimler, The Mobility House and GETEC Group commissioned a LSS consisting of electric car battery modules in Elverlingsen, North Rhine-Westphalia. The **"living spare parts store"** with a total of 1,920 battery modules, an installed capacity of around 9 MW and an energy capacity of 9.8 MWh is available to the energy market for the provision of FCR. Its modular design enables the system to stabilize the power grid with fully automated, uninterrupted control power. Two further second-life storage systems with a total installed capacity of 20 MW (21 MWh) have also been realized by the consortium. They represent the largest fully operational second-life battery storage system in Germany with 1,878 vehicle batteries (The Mobility House 2018).

At one of these storage sites, in Lünen, the waste management company Remondis helped building a capacity of 13 MWh from 1,000 used car batteries. Figure 17 shows how **the second-life use and recycling of batteries** is implemented in Lünen: The battery systems are manufactured and processed at ACCUmotive, a subsidiary of Daimler, which offers electric and plug-in hybrid vehicles. The installation and marketing of the stationary battery on the energy markets is carried out by The Mobility House and GETEC. At the end of the battery's life cycle, valuable raw materials will be returned to the cycle by Remondis in the future (Remondis 2021).

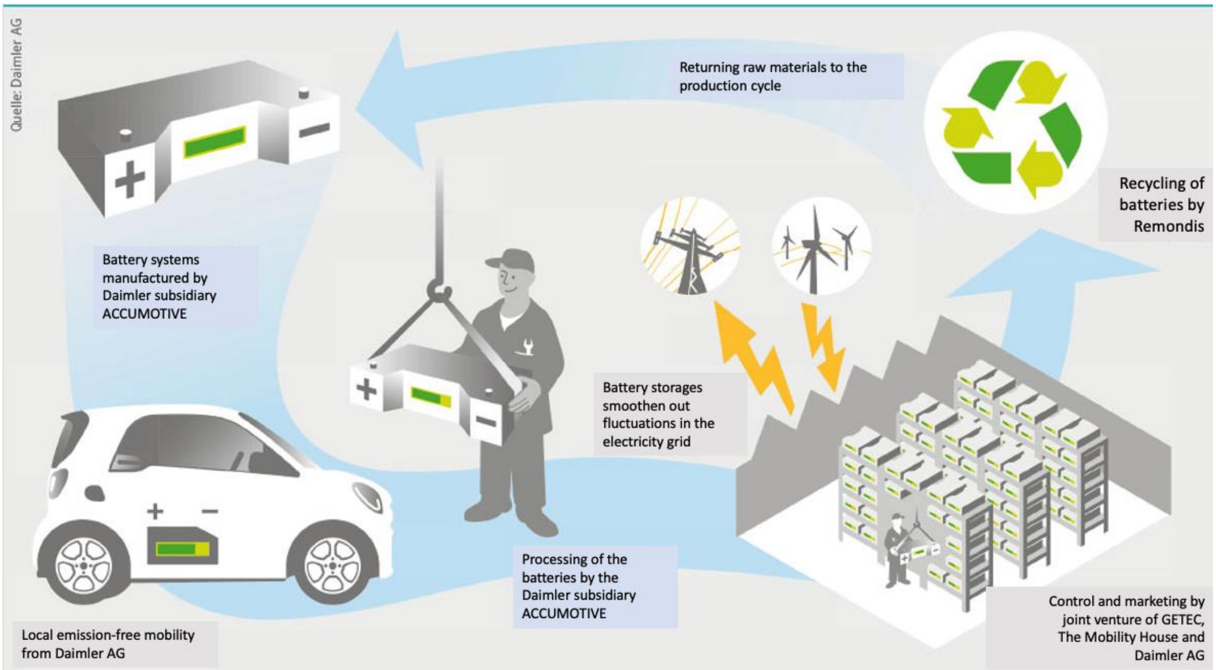



**Figure 17: Second-life and recycling process in Lünen. Source: Remondis (2021), own translation.**

For the **"Second-Life Batteries" project in Hamburg**, the electricity supplier Vattenfall, the car manufacturer BMW and the technology company Bosch have connected around 2,600 used battery modules from more than 100 electric vehicles to form an electricity storage system. The facility in the Port of Hamburg has a size of 2 MW and a storage capacity of about 2.8 MWh and is used in the primary control energy market. Back in 2013, Vattenfall already launched two other second-life projects using BMW batteries with smaller capacities and other use cases. In Hamburg's HafenCity, used batteries were used as temporary storage for fast charging columns. In another application, self-consumption from the photovoltaic system located at Vattenfall's HafenCity heating plant was maximized by temporarily storing energy in these batteries during sunny periods with low electricity demand (Vattenfall 2018).

At the beginning of 2021, the Volkswagen Group launched its own **pilot plant for battery recycling**. In Salzgitter, 3,600 of the carmaker's LIBs can be recycled per year. If the battery is not given a second life or is reaching the end of its second life, Volkswagen will recycle it in the future. To do this, the individual components are first shredded, then the material is dried and sieved. This is how the so-called "black powder" is obtained. It contains the valuable raw materials nickel, manganese, cobalt and lithium. These then only have to be separated individually. Afterwards, they are immediately available for the production of new batteries. The pilot plant in Salzgitter is to be followed by other decentralized recycling plants in the next few years. The Volkswagen Group has set itself the long-term goal of recycling 97 percent of all raw materials (Volkswagen 2021).

The car manufacturer Audi and the materials technology company Umicore have developed **concepts for a closed cycle for components of high-voltage batteries**, which can then be used again and again. In a first step, Umicore and Audi determined the possible recycling rates for battery components such as cobalt, nickel and copper. The result was that more than 95 percent of these elements can be recovered and reused in the laboratory test (Umicore 2018). Based on these results, the partners developed concrete recycling concepts. The focus here is on the so-called closed-loop approach. In such a closed loop, valuable elements from batteries flow into new products at the end of their life cycle and are thus reused. The partners currently cooperate on a closed loop for cobalt and nickel. The recovered materials will be used in new battery cells (Umicore 2019).

Audi is furthermore cooperating in a second-life project with the social enterprise Africa Greentec, which is electrifying villages in Mali and Niger with decommissioned battery storage elements from Audi E-Tron cars (FR 2021).

The recycling companies Erlos and Duesenfeld offer **mobile reprocessing plants** for the recycling of car batteries. With mobile recycling containers from Duesenfeld, LIBs are crushed on site at collection points and the electrolyte is extracted without emissions. The smallest local processing finds space in two 40-foot containers. Thereby, valuable secondary raw materials such as ferrous and non-ferrous metals, the electrolyte and the black mass can be transported safely and efficiently to further processing under lower constraints and costs (Duesenfeld 2021).

### 3.2.2 Studies on regulatory frameworks

*Using BEV batteries for grid services*

Based on their analysis (see chapter 3.1.1), Hildermeier et al. (2019) make the following suggestions for the European market und policy design to further promote the use of BEVs for grid services. Little of this has been implemented in Germany so far.

- Smart pricing should draw on **full flexibility** and provide EV users with fair prices for their services: According to Hildermeier et al. (2019), there are two crucial requirements for creating a suitable framework for dynamic pricing. First, it is critical that real-time energy prices are based on the full value of flexibility on the demand side. Second, electric vehicle users should be subject to fair retail tariffs for energy charges and network fees. This means that all users should reap the benefits of smart charging and, in equal measure, should bear their rightful share of the costs for uncontrolled charging.
- Leverage smart pricing with **responsive technology** to generate substantial benefits: Policymakers are able to maximize the benefits of time-varying pricing by ensuring responsive technology is broadly available to consumers. To this end, EU Member State have to comply with existing legislations on smart meter rollout thoroughly and swiftly, and revise standardization requirements to ensure broad distribution of market solutions. The UK, for example, is considering whether it should require all new, non-public EV charging infrastructure to have the ability to react to price signals.
- **Grid-friendly charging infrastructure** as a key to minimizing costs: In order to ensure future charging needs for different groups of EV users can be met, it is important to implement an integrated approach to energy and transport planning. Building codes should be revisited with a view toward facilitating vehicle charging at workplace and residential settings, including multifamily homes. It is also crucial to direct infrastructure funding in a way that bolsters the development of a competitive market for EV charging services. Municipalities can support this, for example, by including performance indicators in public tenders.

*Using stationary batteries for grid services*

The current German regulatory framework holds some challenges for the full deployment of batteries as grid-serving entities. First of all, the German energy law distinguishes between generation, consumption and transport and lacks a separate definition for storage facilities. Instead, batteries are classified as consumers when storing energy and as producers when discharging energy, which leads to a double burden: Generation is charged according to its own set of rules and consumption according to another one. This legal setup unsettles investors, all the more because at the same time, other governmental measures encourage them to invest in storage facilities (Tepe et al. 2021).

These challenges apply to LSS, ISS as well as households. In addition, a single HSS is currently not allowed to participate in the balancing energy market, as a minimum output of 1 MW for primary balancing power and 5 MW for secondary balancing and minute reserve power is prescribed. The remedy is to combine many small plants into a virtual large-scale storage facility (see also Ninomiya et al. 2019). The provision of balancing power from pooled, decentralized battery storage is already economically viable in Germany, although billing mechanisms and the distribution of grid and EEG levy costs are still open (BEE 2015). Based on an announcement in September 2019 in the “Klimaschutzprogramm 2030” by the German government, the energy storage operators of LSS should be exempted from the final consumer levies, although the classification as final consumer still holds (Federal Government 2019b).

Tepe et al. (2021) conducted a survey among 50 battery storage manufacturers, project developers, grid operators, consulting companies and research institutions during a battery storage expert forum of the German Federal Energy Storage Association in late 2020. They found that two-thirds of the participants at the expert forum cited "regulatory barriers" as the biggest obstacle to a wider use of battery storage in an industrial context. With regard to storage in general, they also named the "double burden of business models with taxes and levies", a "lack of legal and investment security overall" and the "excessive requirements for metering and billing concepts" as the greatest challenges for the economic operation of storage in Germany (see Figure 18).

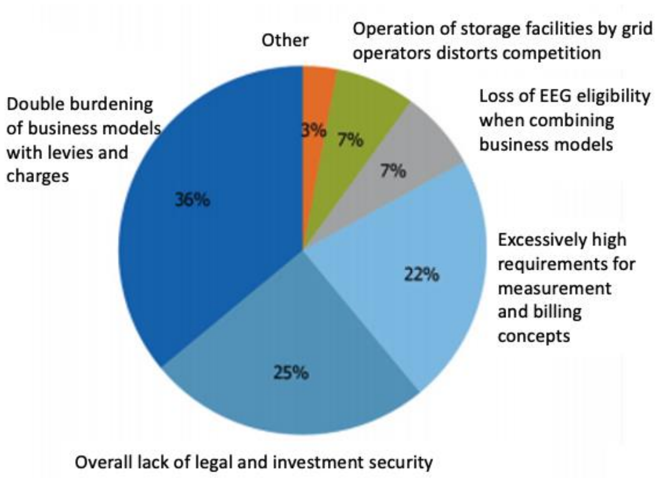



**Figure 18: Survey of 50 experts on the greatest challenges for economic storage operation in Germany. Source: Tepe et al. 2021, own translation.**

The EU Green Deal policy initiative and its concrete legislation address some of these challenges for investors and households. The Electricity Market Directive, which came into force at the beginning of the 2021, provides for a clear definition of energy storage systems. Its goal is to assign energy storage systems a clear role in the energy system and to unburden them of multiple or double levies, surcharges and taxes. In terms of state-induced costs, they must be on an equal footing with energy producers and consumers in the future (Tepe et al. 2021). An improvement in the regulatory framework for stationary energy storage in Germany is therefore to be expected.

*BEV batteries reuse and recycling*

The European Parliament currently works on a new regulatory framework for batteries (European Parliament 2021) in order to secure the sustainability and competitiveness of battery value chains. The Directive on batteries and accumulators, last amended in 2018, is the main legal act regulating batteries at EU level (Eur-lex 2018) and supposed to be preplaced by the new proposal. The innovations relevant for battery reuse and recycling are:

- The establishment of a new category of EV batteries, alongside the existing portable, automotive and industrial battery classes.
- Requirements to minimize the carbon footprint of EV batteries and rechargeable industrial batteries.
- A recycled content declaration requirement. Mandatory minimum levels of recycled content would be set for 2030 and 2035.
- Increased recycling efficiency targets for lead-acid batteries (recycling of 75 % by 2025, rising to 80 % by 2030) and new targets for LIBs (65 % by 2025, 70 % by 2030). The proposed regulation also envisages specific material recovery targets, namely 90 % for cobalt, copper, lead and nickel, and 35 % for lithium, to be achieved by the end of 2025. By 2030, the recovery levels should reach 95 % for cobalt, copper, lead and nickel, and 70 % for lithium.
- Requirements relating to the operations of repurposing and remanufacturing for a second life of industrial and EV batteries.

- Labelling and information requirements necessary for the identification of batteries and of their main characteristics. Rechargeable industrial batteries and EV batteries should contain a battery management system storing the information and data needed to determine the state of health and expected lifetime of batteries.
- Creation of a battery passport (i.e. electronic record) for each industrial battery and EV battery placed on the market or put into service.
- Development of minimum mandatory green public procurement criteria or targets.

Although those measures are about to solve some of the challenges described in chapter 3.1., there is still a need for further clarification. In a workshop with representatives from OEMs conducted by Olssen et al. (2018), legislation and responsibility were discussed as main issues to be clarified to stimulate more circular business models in battery reuse and recycling. In the EU, the actor that puts the battery on the market has producer responsibility, i.e., responsibility for providing a system for collection and recycling when the battery becomes waste. That responsibility can be transferred if the battery turns into a new product, with a new function or under a new brand. It is not always entirely clear which actor has the producer responsibility, and uncertainty about legal issues could discourage actors from engaging in second-life endeavours.

## 3.3 Japan

### 3.3.1 Study and demonstration for utilizing home/commercial batteries and EV batteries as distributed resources in Energy Resources Aggregation Business Development (ERAB) Projects

METI started the Virtual Power Plant demonstration project in 2016. The Energy Resources Aggregation Business (ERAB) demonstration project intends to remotely control distributed energy resources, such as home batteries, EV batteries, demand responses, and self-generations, as if the aggregated resources may function as a consolidated virtual power plant. The project includes evaluation of the remote control/operations under the grid operator's command, developing communication protocols and systems, and validating the remote-control technologies using real onsite pieces of equipment and systems. The project also tries to understand the barriers and challenges towards the business cases developments using virtual power plant controls.

#### 3.3.1.1 The case of Battery Electric Vehicles (BEV): demonstrations of change in EV charging behaviours by use of dynamic electricity rates

Vehicle electrification has become one of the top priorities in many countries with the carbon-neutral target, and the electricity demand increased by EV charging will become an increasing challenge for most power businesses in the world. While EV charging is a big demand increase factor both in the total electricity usage as well as the load peak, there is a big chance to manage the charging schedule to avoid the power system load peak time. Increasing renewables and IoT controllable devices will introduce smart pricing power menus, reflecting the lower price when renewable sources are widely available or the higher price when the demand peaks with less renewable generations (Figure 19).

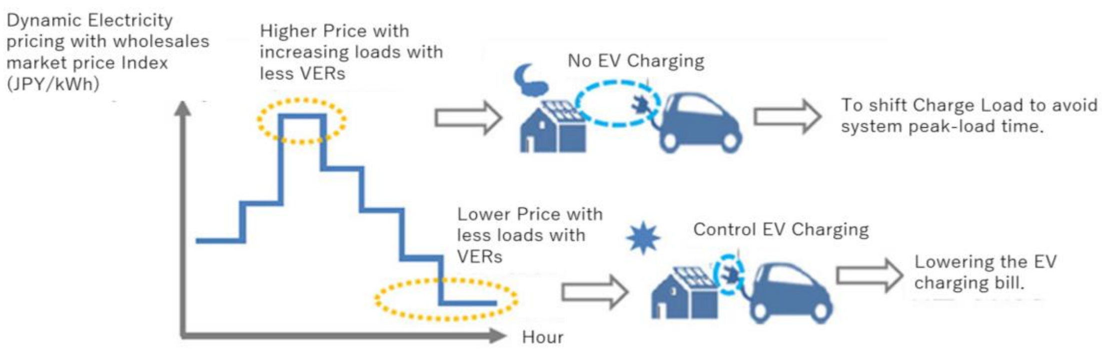



**Figure 19: EV charging behaviour change program, Kansai VPP Consortium.**

Kansai VPP consortium had carried out a series of EV charging behaviour change tests, with a dynamic electricity price, reflecting the wholesales traded power price. The dynamic pricing has lower price tag during renewable electricity available hours, between 10 am and 2 pm. A typical daily charging result is shown in Figure 20, the hourly EV charging amount of controlled 32 EVs. When there is no dynamic pricing, most EVs are charged after 10 pm until the vehicles use starting from 7 am. When the dynamic pricing is introduced that the mid-day between 10 am and 2 pm electricity price is the lowest, EV users did change the charging hours. The program conducted the user's behaviour-based charging test as well as the automatically controlled charging test. In the former test, EV users received price information, and users decided when to charge their EVs, while in the latter test, EV users did not decide when to charge, the remote EV charging system decided when to charge. The tests showed behaviours change in both tests, shifting the charging time to less expensive hours. The latter test, using the smart remote charging system, had a larger cost-saving as well as fewer hassles for EV users.

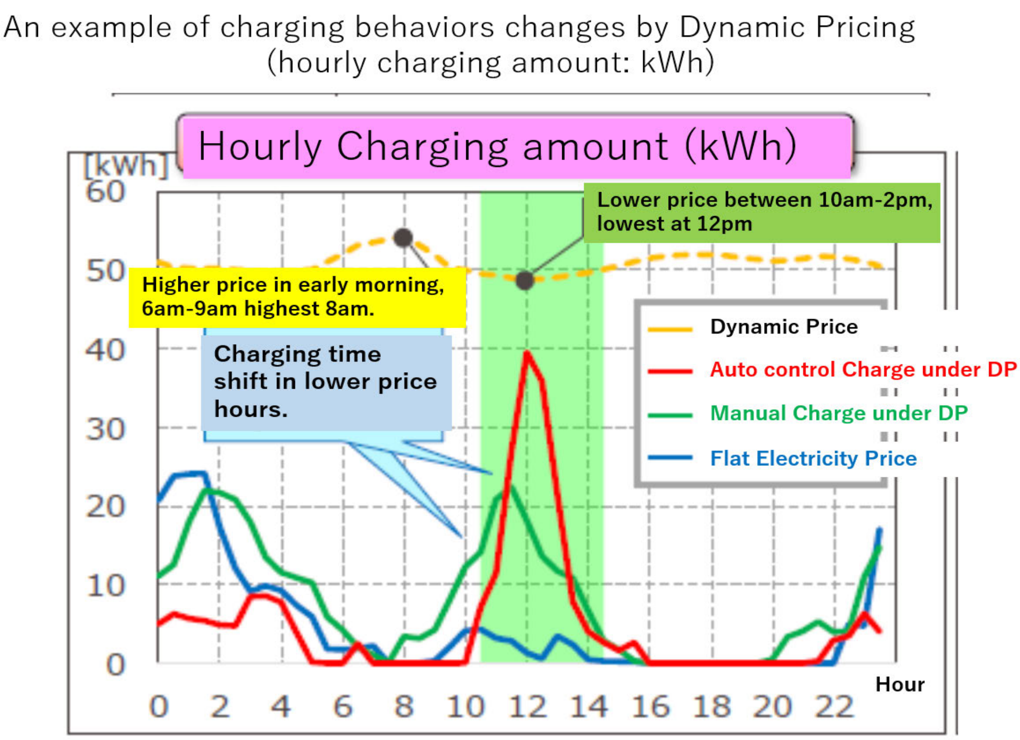


Figure 20: A typical result of Kansai VPP Consortium's EV charging behaviour change.

#### 3.3.1.2 Using BEV batteries in buildings or grid-integrated demand-supply balancing: Demonstrations of the virtual power plant concept and the insights from the experiences of the project

A series of demonstration and validation field tests have been conducted under Program1 "Demonstration of the Virtual Power Plant Concept", including the communication-control technologies for the remote control, the implementation of remote control for various distributed resources, and metering issues. Field tests have been conducted with step-up test conditions reflecting actual grid resources service requirements. A few consortiums were developed, with the consortium leader, the Aggregation Coordinator, and several Resources Aggregators and Resources Providers.

Table 13 shows the largest consortium members in the "Kansai VPP Validation Project", and the schematic chart of the Kansai VPP Project is shown in Figure 21.

Table 13: Kansai VPP consortium, members and resources.

| | | Battery | | | Residential | | Commercial | | S Gen Fridge | EV | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Res | Ind | Util | EQ | HMS | A/C | W P | | Chg | V2H |
| AC | KANSAI Power | | | YES | | | | | | YES | YES |
| R AG | Shikoku Power, Sharp, | | YES | | | | | | | | |
| | Mitsubishi Corp, Kyocera, Panasonic, LOOOP | YES | | | | | | | | | |
| | Enegate | YES | | | YES | YES | YES | | | | YES |
| | Sumitomo Electric | | | YES | | | YES | | YES | YES | |
| | Daihen, Kinden | | YES | | | | YES | | | | |
| | Yokogawa, Hitachi, EON Delight, Fukushima Garay | | YOK | | | | | YES | YOK | | |
| | Hokuriku Power | YES | YES | | YES | YES | | | | | YES |
| | NTT Smile Energy | YES | | | YES | | | | | | YES |
| R PR | Sannshadednki, Sumitomo Corp, Delta Denshi, Nichikon, Benex, Yamabayashi, Elly Power | YES | YES | YES | | | | | | | |
| | ENEOS, Fuji Electric | | YES | YES | | | | | | | |
| | Nihon Unisys | YES | | | YES | | | | | | |
| | Idemitsu | | | | | | | | | | YES |

AC: Aggregator Coordinator, R AG: Resource Aggregator, R PR: Resource Providers
Battery: Residential/Industrial/Utility Scale, Residential Resources: EQ=Heat Pump Boiler, HMS: Home Management System, Commercial Demand Response:
A/C=Air Conditioner, WP: Water Pumps, Self Generation, Commercial Regrigerator, EV Charging, Vehicle to Home

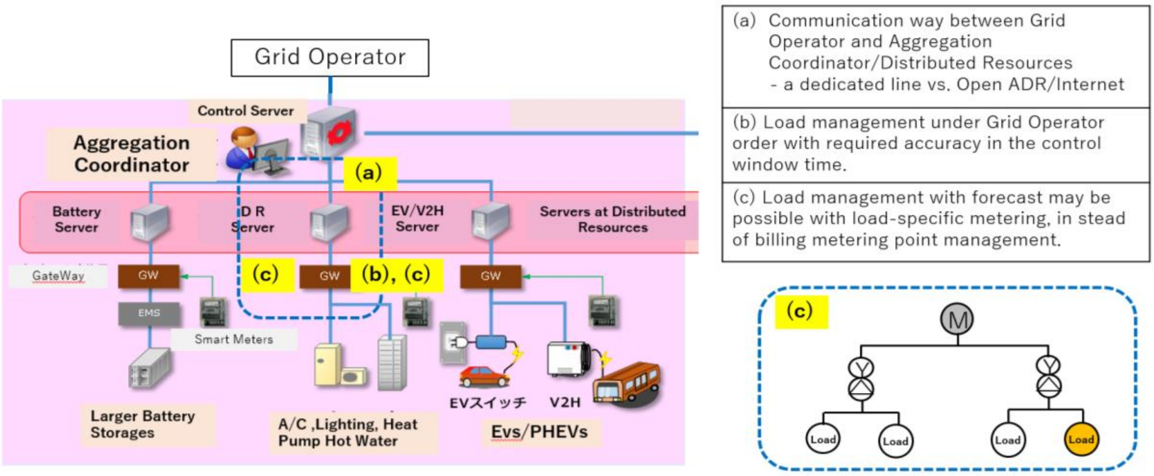



**Figure 21: Kansai VPP Consortium, a schematic of resources aggregation as VPP.**

*Insights from the demonstration projects*

(a) Development of communication standards, validation of the reliability of control by Open ADR and Internet line

In the case of large-scale power plant operation and communication with the power grid operator, the communication and the control use a dedicated line. In the Virtual Power Plant, such a dedicated line use across the numbers of smaller distributed resources is not economically feasible. The project validated the remote control and the communication by the use of widely available communication tools, such as high-speed internet. The communication protocols have been tested and the results showed acceptable reliability and accuracy.

(b) Reliable operation verification of resources under the grid operators' commands

Distributed resources need to be safely and accurately controlled by the grid operators' commands to contribute to the grid operation stability. The projects conducted a series of field tests under the RR-FIT service condition with providing negative demand responses.

(Table 14 shows the Type 3-2 RR-FIT (Replacement Reserve for FIT) service condition and Type 3-1 RR (Replacement Reserve) service condition)

**Table 14: Control requirement under RR-FIT service and RR service (negative demand response).**

| | Type 3-2 (RR-FIT) Negative DR | Type 3-1 (RR) Negative DR |
|---|---|---|
| Control Change | Yes (3 changes in 3hrs window in the 2020 field tests.) | |
| Control Change Interval | 30 min. | 1 min. |
| Response Time | 45 min. | 15 min. |
| Duration Window | 3 hours | |
| Reference Load | Aggregators nomination with 30mins resolution | |
| Control Accuracy Requirement | 10% accuracy to reference load | |
| Minimum Load | > 1MW | |
| Nomination Schedule | Prior day, 3hrs data | Previous week Friday, one-week-3hrs data |

*Industrial battery*: Most resources at stable loads showed an accurate forecast of the base reference load with successful control performances under the grid operators' commands. Among the field tests, there was a case at Load Site "C" with the load fluctuation exceeding the battery capacity, which brought a challenge of setting the base reference load. Most of the field tests used relatively large capacity reserve, which is not always available in much industrial battery installed customers. The tests also revealed a potential barrier to the RR-FIT service rule. The current RR-FIT application process requires an applied resource that should meet the control accuracy to be met in 5 minutes window, while the service only requires 30 minutes window control. Most of the resources showed accurate 30 minutes window control, using a minute resolution data communication. Such a 1-minute communication resolution is not good enough to maintain the accuracy in the 5 minutes control window, instead, it may require higher resolutions. This application approval process rule should be re-visited.

*Home Batteries*: In many cases, home batteries could not meet the RR-FIT service requirement. Most of the home batteries in the field operate as no discharging when roof-top PV generates electricity, and as maintaining the maximum storage level in the early evening when the rooftop PV power generations decrease. RR-FIT services are usually expected in early evening hours, while many home batteries do not by design discharge during those hours. This finding is not a technologies barrier, but the result gives insights that some resources may not be practically available.

*EV batteries*: EV batteries can become promising resources in RR-FIT services without compromising the EV transportation functions, as long as the EV use scheduling is accurately available. In that sense, commercial use EV vehicles scheduling should be available with reasonably good accuracy for the use of RR-FIT services, except the 3 hours consecutive use for RR-FIT services requirement can become a business barrier. The current RR-FIT service requires a single control resource should serve in an aggregation group for consecutive 3 hours. Smaller resources, such as EV batteries, are serving as an aggregated group, and there are enough aggregated resources while an individual resource can contribute less than 3 hours. The tests on the RR-FIT service also revealed the major challenge in the baseload reference nomination rule. TSS service rule requires a weekly reference load data to be submitted on the last day of the previous week, an entire weekly vehicle scheduling on the previous Friday tends to be less accurate in real business fields. RR-FIT service requires the daily reference load data submission on the previous day. Such one day ahead vehicle scheduling is more accurate and very manageable.

(c) Control metering points, the billing meter point vs. the control resource point metering

The field tests gave important lessons on the control metering point. The services transactions are made based on the resource control operation matching the control demand and the current services are procured by the smart-metering point electricity load (M in Figure 21). As shown in the schematic figure in Figure 21, the smart-metering point, which is the electricity purchase transaction measurement point can measure more than one equipment/system. When there is a larger fluctuating load or the roof-top PV is metered with a control device (resource), the smart-metering point measurement may have a large fluctuation of load, even if the control device perfectly matches the grid demand. Smaller home batteries, smaller commercial batteries, and smaller demand responses will be practically prevented from contributing to an aggregated resource as long as the service rule allows the control device load metering. It is also advised that uncertified metering techniques should be allowed to avoid the much higher cost of certified meters.

#### 3.3.1.3 The Study and Demonstration Project (ERAB) programs between 2021 and 2023

The ERAB demonstration project continues a series of field testing to promote distributed energy resources use in new businesses. From 2021, the follow-up series of field tests are carried out, including these two tests.

- More demonstrations of the dynamic pricing effect on the EV charging behaviours

  Different types of dynamic pricing are introduced in the field tests, reflecting the wholesale market renewable power supply. The self-decision system with longer days with the actual wholesale market price is tested. The program is also developing new dynamic pricing along with the test use of apps, which will help EV users to understand the smart EV charging under the dynamic electricity pricing.

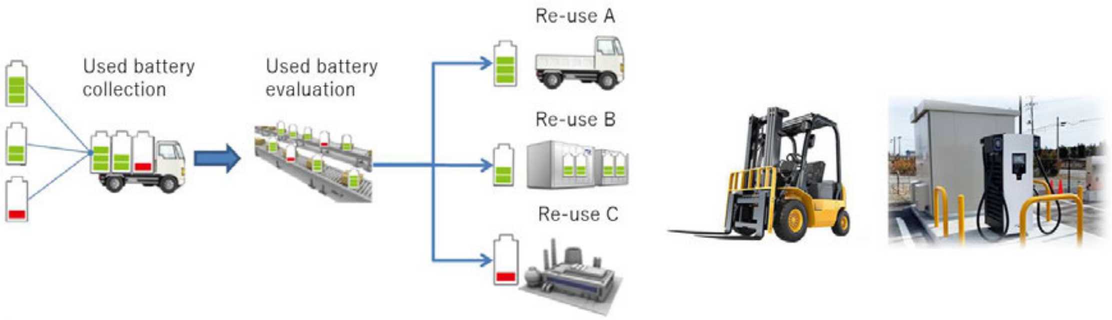
- Demonstration of more mixtures of aggregated resources

  The field test intends to understand the actual renewable power supply changes and the simulations on the supply-demand balancing with test-controlled aggregated resources. A different set of aggregated resources will be tested, including the discharge from battery resources and self-generations. Tests are also expected with the control requirements by the new services, Type2-2 FRR (Frequency Restoration Reserve) and Type2-1 S-FRR (Synchronized Frequency Restoration Reserve).

#### 3.3.1.4 Experiences on battery 'second life' and recycling

Nissan Motor has been long working on technology and business trials on the re-use, re-purposing, and recycling of EV batteries. Nissan started selling their first BEV model, Leaf in 2010 and Nissan also launched a new business arm, FOR-R Energy jointly funded by Sumitomo Corporation. FOR-R has been working on the evaluation techniques of Leaf batteries, re-use as EV battery, re-purpose for less-demanding use, such as a forklift battery, a golf-cart battery, and a stationary battery.

Before scraping the battery for material recycling, a used EV battery may be suitable as a backup/emergency stationary battery. Figure 22 shows business fields of EV battery re-use by FOR-R Energy. Mr. Makino, CEO of FOR-R Energy suggested challenges and business perspectives in BEV battery recycling in the media interview in 2021 (Xtech 2021). FOR-R started the re-use/recycling business in 2010, a month before Nissan launched the Leaf. Makino understood the re-use/recycling of BEV battery depends on how fast and accurate FOR-R can evaluate the remaining capacity. FOR-R could not advance in this technology, because there were no used Leaf batteries. It was around 2017 FOR-R started collecting the first batches of Leaf batteries. FOR-R built a reuse/recycling dedicated plant in 2018 and they started learning the battery evaluation. By then, FOR-R had tried several re-use applications, such as electric power forklifts, backup power for shelters and rail crossing bars, and street lights, using new batteries. After 11 years since the Leaf launch, Nissan and FOR-R are expecting to receive sizable used Leafs, as much as 2,000 units in 2022. FOR-R can evaluate the battery capacity in 4 hours, and they are working on the improvement. Mr. Makino told the media that he is not expecting the business growth soon. He said the re-use/recycling business growth will be in 5-10 years range, and the close work with Nissan is essential. Makino told that FOR-R has the second task in EV battery reuse and recycling, which is improvement of EV valuation in the used car market. It is widely known that the value of the first generation of Leafs dropped much faster than for conventional engine cars, as much as 60 % drop in the first year, and residual values could be low as 15 % after 4 years. Remaining battery capacity has been hardly known by most used car dealers and used Leafs have been unpopular in the second car market due to battery deteoration concerns. FOR-R and Nissan are trying to improve the Leaf's residual values with transparent EV battery's capacity valuation.




| Re- Use: A | EVs, EV-Bus/Trucks |
|---|---|
| Re-Use : B | **Battery powered Forklift,**<br>Battery powered Golf-cart<br>Industrial Stationary Battery Storage<br>**EV Charging Station Battery Storage** |
| Re-Use : C | Backup Emergency Power Supply<br>(**Rail-Crossing, Street Lights**,<br>Shelters, Medical Centers…) |

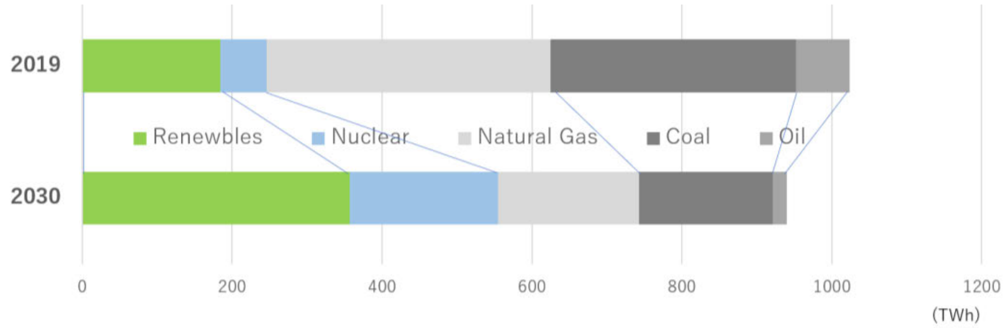

http://www.cev-pc.or.jp/xev_kyougikai/xev_pdf/xev_kyougikai_wg02-1_about_WG.pdf
電動車活用社会推進協議会　車載用電池リユース促進WG　資料4　2019年12月25日　経済産業省　電動車活用社会推進協議会

Figure 22: BEV battery second-life use cases by Nissan-FOR-R ENERGY.

### 3.3.2 Regulatory framework

#### 3.3.2.1 Japan pledged 2050 carbon neutrality, grid stability balancing resources will be required along with the increasing renewable generation and decreasing fossil-fuel generation

The Japanese government declared in October 2020 that it would aim to realize Carbon-Neutrality by 2050, and then-Prime Minister Suga announced the new 2030 GHG reduction target by 46 % reductions from 2013 at Leaders' Summit held in April 2021 (Suga also mentioned his determination to aim for a further 50 % reduction). To realize such pledges, discussions on the 6th Energy Basic Plan, which is the basis of energy policy, proceeded and the 6th Basic Energy Plan (BEP 2021) was published on October 22nd. BEP 2021 intends to introduce a large share of renewable energy power (36-38 %), and renewable energy and nuclear will become the two pillars of future power sources. The plan also proposes a significant and fast reduction of fossil fuel dependency (76 % in 2019 → 41 % in 2030) (Figure 23).

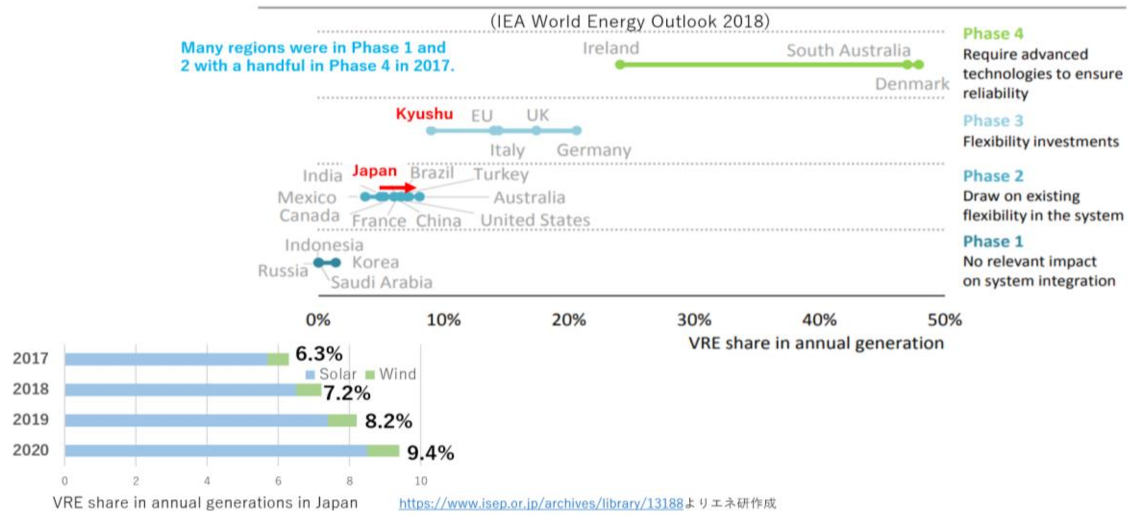



https://www.enecho.meti.go.jp/committee/council/basic_policy_subcommittee/2021/046/046_004.pdf
総合資源エネルギー調査会 基本政策分科会（第46回会合）2021/07/21
資料1 エネルギー基本計画（素案）の概要

**Figure 23: Renewable powers will increase towards 2030: Basic Energy 2021 (2021/10/22).**

Due to the increase in renewable energy use in recent years, METI and the electricity sector are already aware that the new electrical power system will require a substitute of supply stability measures, replacing fossil fuel thermal power plants, which so far have performed the function to maintain the demand-supply balance and the stability of power supply.

When the new balancing resource discussion started in 2018, the amount of renewable energy, especially Variable Renewable Energy (VRE) generation share was 6.3 % in Japan (2017). IEA Energy Outlook 2018 suggested the need for additional flexibility of power resources along with the increase of VRE generation shares by templating the 6 Phases (Figure 24) and 2018 Japan was corresponding to IEA-Phase 2: Draw on existing flexibility in the system (Kyushu had higher VRE ratio, corresponding Phase 3: Flexibility investment in all measures). The 2020 VRE ratio increased to 9.4 %, and it is now entering Phase 3, and the 6th Basic Energy Plan's renewable energy ratio of 36-38 %, in which the VRE ratio of generation, estimated at 53 %, corresponds to the later Phase 4. It is a more critical and urgent issue to prepare the flexibility measures than the initial discussion in 2018 because the VRE share will rapidly increase by the mid-2020s. METI intends to use available distributed energy resources for the demand-self balancing, including self-power generation, demand response with lighting-air conditioning-industrial processes, and the battery storages including EVs.

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再生可能エネルギー大量導入・次世代電力ネットワーク小委員会（第18回）再生可能エネルギー主力電源化制度改革小委員会（第6回）合同会議 2020/7/22

**Figure 24: VRE share increase will require additional supply-demand balancing measures.**

#### 3.3.2.2 Green Growth Strategy (June 2021) includes “Mobility/ Battery” as one of the key growth areas toward carbon neutrality

The Japanese Government battery storage strategy is comprehensively described in "The Green Growth Strategy", revised with Action plans in June 2021. The Green Growth Strategy is an industrial policy which aims to create a positive cycle of economic growth and environmental protection. "Mobility/Battery" is one of the 14 sectors in the strategy.

Regarding Mobility electrification, Japan falls behind Europe and China in the widespread use of BEV and PHEV vehicles, in the first quarter of 2021, approximately 350,000 units in the EU (more than 1.5 times as many as in the same period of 2020) and approximately 11,000 units in Japan (20 % more than in the same period of 2020) were sold.

Japanese Government holds the position to use technology-neutral mobility development toward carbon neutrality, "electrically driven" vehicles should consist of electric vehicles, fuel cell vehicles, plug-in hybrid vehicles and hybrid vehicles. Each country and the market has a pathway to decarbonize the power generation as well as the economic status and the best-suited vehicle electrification is required to achieve the gross GHG emission reduction.

RoadMap, Action Plans: Automobile (related to electrifications and batteries):

- 100 % of new passenger vehicle sales being for vehicles that are electrically driven by 2035.
- Commercial vehicles, for light-duty vehicles (8 tons or less), 20-30 % of new vehicle sales to be electrified vehicles by 2030, and 100 % of new vehicle sales to be electrified vehicles and vehicles suitable for the use of decarbonized fuels such as synthetic fuels combined by 2040.
- Large vehicles (over 8 tons), 5,000 units of electrified vehicles in the 2020s, set to re-visit the target of 2040 by 2030, with the progress of hydrogen and synthetic fuels.

- Expanding the introduction of infrastructure. To install 150,000 charging points by 2030 the latest, including 10,000 quick chargers at gas service stations (SS), and 30,000 public quick chargers. To install 1,000 hydrogen stations by 2030.

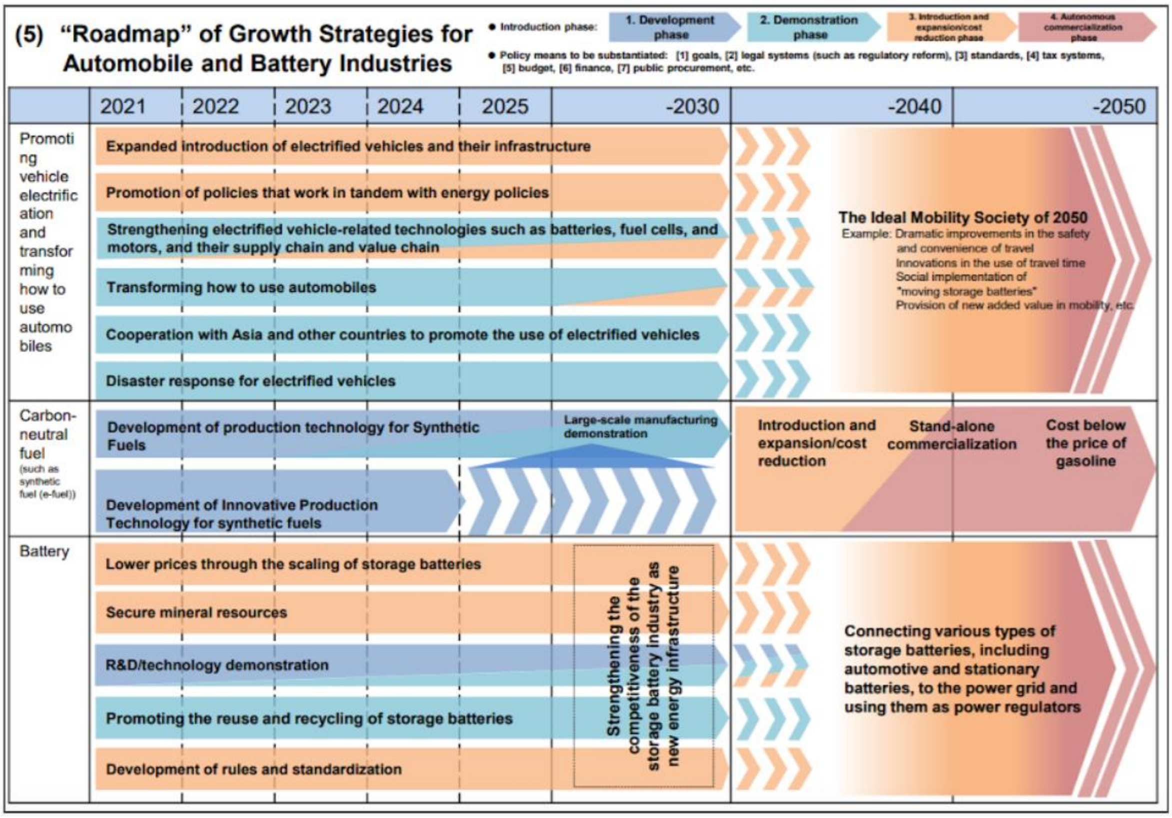
RoadMap, Action Plans: Batteries:
The market for on-board storage batteries is expected to grow with increasing electrification of automobiles, and the need for stationary storage batteries is also expected to expand. The storage batteries are also a "new energy infrastructure" that will play a key role in the advancement of carbon-free power sectors, with the increasing renewable energy.
The securing of storage batteries and the stabilization of supply chains are important issues when promoting electric vehicles. Electric vehicles need storage batteries with a capacity 50 to 100 times greater than that of hybrid vehicles, and 10 to 20 times greater than that of plug-in hybrid vehicles.
The Green Growth Strategy includes the battery production capacity increase target as well as securing the supply value chains of batteries.

- The domestic manufacturing capacity for automotive storage batteries will be increased to 100 GWh as early as possible by 2030.
- In addition, the aim is to achieve a cumulative introduction of approximately 24 GWh by 2030 (approximately 10 times the cumulative amount introduced by 2019) for household and commercial/industrial storage batteries in total.
- Lower prices through the scaling of storage batteries productions/sales
  - ➢ an onboard storage battery pack price of 10,000 yen/kWh or less
  - ➢ a household storage battery of 70,000 yen/kWh or less (including installation costs)
  - ➢ a commercial/industrial battery of 60,000 yen/kWh (including installation costs)
- Secure mineral resources.
- Promoting the reuse and recycling of storage batteries: R&D and technological demonstrations will be undertaken in order to reuse them as vehicle-mounted parts or stationary storage batteries if they can be reused after initial use, and to efficiently recover mineral resources if they can no longer be used. In addition, standardization and the institutional framework for promoting the reuse and recycling of storage batteries will be studied.
- Regulation development and standardization.

In order to promote the reuse of on-board storage batteries and their reuse as low-cost stationary storage batteries, Japan should work on international standardization of methods for evaluating the residual performance of storage battery packs and the performance and safety of stationary energy storage systems, including reused storage batteries.
Works are expected to increase in evaluating the value of stationary storage batteries toward the power grid supply and demand adjustment market (to be fully operational in 2024). In order to promote new businesses that utilize large-scale grid storage batteries, the positioning of grid storage businesses under the Electricity Business Act will be clarified, and the process of jointly procuring grid storage batteries will be implemented in order to address the lack of short-term reserve capacity with increasing variable generations from renewable energy sources. Furthermore,

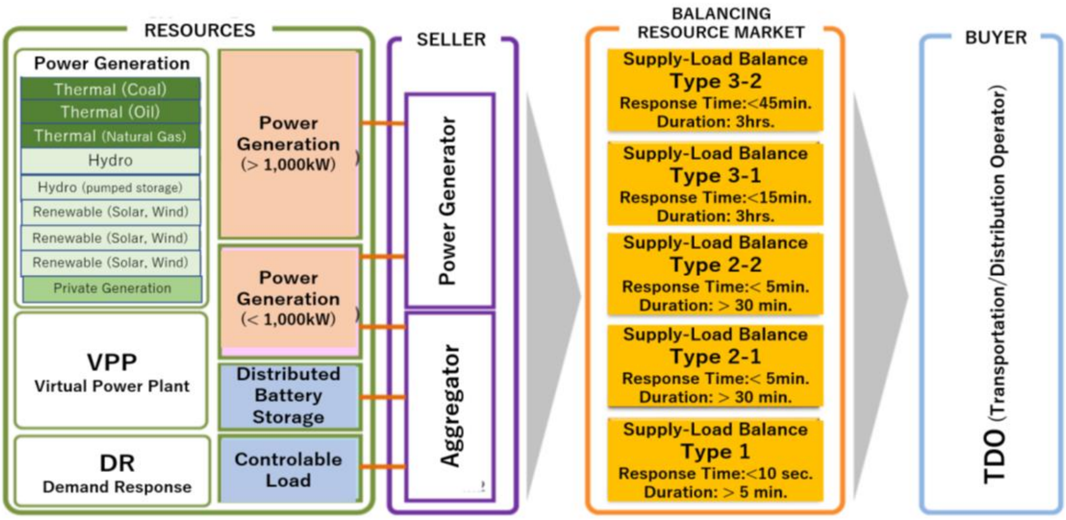
in anticipation of the use of aggregated smaller storage batteries resources to adjust supply and demand, a new grid code for storage batteries use has to be developed.

**Table 15: The Green Growth Strategy, Roadmap of "Automobile and Battery Industries" (June 2021).**




### 3.3.2.3 Supply-Demand Balancing resource to be procured by creating the new reserve service market

Until the 2000s, regulated power utilities, that vertically integrating power generation, transmission/distribution, and retail supply, were responsible for maintaining the demand-supply balance and the power supply stability. They maintained the supply-demand balancing and the supply stability by operating their resources, such as thermal and pumped-storage hydro power plants. The deregulation of electricity retail supply began in 2000, and the market sectors were gradually opened for competition. The transmission/distribution business accounting separation was required in 2003, and the 2013 Power System Reform discussion eventually concluded the necessity of legal entity separation, which became effective in April 2020. The legally separated transmission-distribution grid operators (TDO) will take over the supply-demand balancing and supply stability. The reform demanded that TDO companies are responsible to maintain the supply stability, but the TDO companies do not own supply stability resources, they should use resources owned or secured by power generation companies and retail supply companies. TDOs currently make bilateral procurement contracts and METI plans to develop an open market where TDOs can procure balancing resources. METI and the industry have been working on the new balancing resource market, to allow efficient use of available balancing resources (Figure 25).

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第43回 総合資源エネルギー調査会 電力・ガス事業分科会 電力・ガス基本政策小委員会 制度検討作業部会 資源エネルギー庁　2020年10月13日　資料4-1　需給調整市場について

**Figure 25: Supply-Demand Balancing resource market proposal.**

The proposed balancing resource market will have a series of balancing resource services, with different requirements (shown in Table 16). Type 3 service, maintaining the supply-demand balance, may start in 2022 and more critical grid-stability control resources, Type 2 and Type 1 services may start in 2024.

**Table 16: Supply-Demand Balancing resources classification.**

| | Type 1 Frequency Containment Reserve (FCR) | Type 2-1 Synchronized Frequency Restoration Reserve (S-FRR) | Type 2-2 Frequency Restoration Reserve (FRR) | Type 3-1 Replacement Reserve (RR) | Type 3-2 Replacement Reserve for FIT (RR-FIT) |
|---|---|---|---|---|---|
| Calling events | Hourly fluctuations and unexpected supply failure | Hourly fluctuation and unexpected supply failure | Hourly fluctuation | Hourly fluctuation and unexpected supply failure | Fluctuating FIT renewables |
| Communication | Automation | Online-LFC | Online-EDC | Online-EDC | Online |
| Response Time Window | <10 sec. | < 5 min. | < 5 min. | < 15 min. | < 45 min. |
| Duration Time Window | > 5 mins. | > 30 min. | > 30 min. | Group Block (3 Hrs) | Group Block (3 Hrs) |
| Minimum Volume | 5MW | 5MW | 5MW | 5MW (dedicated online)<br>1MW (internet) | 5MW (dedicated online)<br>1MW (internet) |

https://www.meti.go.jp/shingikai/enecho/denryoku_gas/denryoku_gas/seido_kento/pdf/043_04_01.pdf
第43回 総合資源エネルギー調査会 電力・ガス事業分科会 電力・ガス基本政策小委員会 制度検討作業部会 資源エネルギー庁　2020年10月13日　資料4-1　需給調整市場について

#### 3.3.2.4 METI and industries are working on EV utilization promotion and EV battery re-use

At the New Automobile Strategy Meeting in March 2019, METI officially set a goal of 100 % EVs sales by 2050. At the strategic meeting, attendants pointed that several strategies are necessary to accelerate the automotive electrification, including the development of battery supply chain, reducing risks by materials procurement, and establishing a method for evaluating the remaining performance of lithium-ion batteries.

In July 2019, METI established the "Electric Vehicle Utilization Promotion Council" in which industries such as electric power, logistics, and retail, as well as local governments, participate along with METI and automobile manufacturers. Two working groups were established, the "EV Utilization Promotion Working Group" which discusses the utilization of EVs in the event of a natural disaster, and the "Battery Reuse Working Group" which evaluates the performance of EV batteries.

The "EV Utilization Promotion Working Group" is working to encourage companies and local governments to employ and use EVs in an emergency, such as a temporary energy power supply to evacuation shelters, senior homes, and medical equipment power supply in the event of a power outage due to a natural disaster (storm, flooding, earthquake).

The "Battery Reuse Working Group" is working to establish the EV battery performance assessment standard, so that the EV battery can be re-used as another EV battery, other electrified mobility use, and stationary battery use, and less-demanding backup power battery. This working group found that the remaining performance evaluation standardization can help correctly evaluate used-EVs by reflecting the battery values in the next business use. The working group issued "Battery Performance Evaluation Guideline (1st Edition)" in June 2020. According to this guideline, the configuration, cell shape, and material of EV batteries differ from manufacturer to manufacturer, and excessive standardization may interfere with the manufacture competition. However, it is important to establish a trustful standardized battery performance evaluation method, and the guideline suggests using the relative performance ratio indicating what percentage of the initial performance of the battery is remaining, by using the government- (Ministry of Land, Infrastructure, Transport, and Tourism: MLIT) -authorized one-charge mileage comparison (by 10 % increments). The guideline expected the EV manufacturers to start employing this relative performance evaluation with 2022 model productions.

# 4 Comparison of German and Japanese potentials, business cases and regulatory frameworks

In this study, we conducted research on the policies and deployment status of storage batteries in Germany and Japan, seeking initial examples of the use of power grid-integrated batteries and building-integrated batteries but also battery-electric vehicles. The research has brought many findings, where there are many common perspectives and expectations between Germany and Japan toward storage battery use and deployment, while there are also differences in policy priorities and initial programs. With regard to the different types of batteries and the aspects of their use as flexibilities in electricity markets and grids, their 'second life', and recycling, we found the following facts:

- *Germany has more experiences with grid balancing/flexibility with LSS.*
  There are comparatively many large-scale power-grid-integrated battery storages used in Germany, reflecting the fact that variable electricity generation by photovoltaic and wind resources has exceeded 30 % of total power consumption, and the grid frequency control reserve and the demand-supply balancing resources are more imminent needs in Germany, while such grid frequency control reserve and the demand-supply balancing resources are less required in Japan with the variable electricity generation in Japan remaining as much as 10 %.
- *Germany and Japan are both expecting the increase of HSS to maximize the use of rooftop PV.*
  Japan has already implemented many commercial/industrial battery storages, with a long history of energy efficiency promotion and energy peak-shaving in the sector, and there are many on-site self-power generations and battery storages. In both countries, the market for home storage systems is growing too, but they are not yet widely used for grid flexibility and optimization purposes. In Germany, this is i.a. due to slow roll-out of smart meters.
- *Different policies in BEV deployment.*
  Regarding the battery electric vehicle (BEV) deployment, Germany is in the big movement of Transportation sector's electrification within EU-wide policy movement. The European Commission has proposed a new directive to ban internal combustion engine automobile sales by 2035, and the BEV sales in Germany have already exceeded 20 % of all new car sales in 2020. German experts in energy advise that the BEV's first contribution to the power grid is the flexible management of BEV charging load, avoiding the excessive stresses in the power grid operation and the investment that would be needed to strengthen the grid.
  The Japanese government and the automobile industry maintain the policy of automobile electrification without limiting to BEV but including hybrid cars. The BEV sales in Japan are not growing at the same pace as BEV sales in Europe and Germany.
- *Different approaches in the regulatory frameworks for BEV battery recycling.*
  The European Commission has started the development of BEV battery recycling business chains with the proposed EU Battery Directive. Germany has experience on BEV battery recycling pilot projects with automobile manufactures and industrial recycling specialists.

Japan is taking a different approach by allowing automobile and battery stakeholders to develop a voluntarily action guideline for the practice of evaluation of remaining capacitities of used EV batteries.

There are many findings from the research and they can be grouped in four types of status between Germany and Japan. They are:

A) "Two countries share the perspectives/expectations and they are in the same implementation status."
B) "Two countries share the perspectives/expectations, and Germany is ahead of Japan in implementation."
C) "Two countries share the perspectives/expectations, and Japan is ahead of Germany in implementation."
D) "Two countries share the perspectives/expectations, but there are differences in policy priorities/implementations."

Notable findings are shown below in the four types of comparison status.

**A) Two countries share the perspectives/expectations and they are in the same implementation status.**

- The deployment of Home Storage Batteries and Commercial/Industrial Storage Batteries focuses on benefits of battery storage users so far. There are barely cases where the initial expectation of storage battery implementation involves the grid-integrated use as a source of flexibility.
- Germany and Japan are both expecting the growth of home battery storage deployment in maximizing the roof-top PV generation use, as Feed-in-Tariff advantages over the grid purchase electricity is decreasing. To increase the home battery storage, the cost reduction of home battery storage will help the deployment pace uptake.
- Germany and Europe are increasing investment to secure the battery production capacities particularly for BEVs. In Japan, there will be fewer onboard batteries than in Europe because hybrid vehicles' onboard battery capacity is much less than BEV, however major Japanese automobile manufacturers are starting to invest in battery production capacity towards 2030.
- The experience with pooling of smaller battery storage (HSS or BEV) in both countries is rather low. There is only one viable business case in Germany on aggregating HSS as a VPP (see also B)). In Japan, a demonstration program on VPP has been found.
- For all of HSS, C/ISS, and BEV, both countries still need to develop the regulatory frameworks, in technical and economic terms, that will enable their widespread use as flexibility resources for the electricity markets and grids.
- Regulatory frameworks also need to be improved for second-life uses and recycling of batteries.

**B) Two countries share the perspectives/expectations, and Germany is ahead of Japan in implementation**

- As the variable electricity generation resources such as solar power and wind power increase and the thermal generations decrease, it is conceivable to use battery storage as a means of securing grid stability function and the supply-demand balancing function. A large-scale grid-integrated battery storage may play the first role in such an expectation due to lower investment and control costs, and there are already 68 grid-integrated battery storage systems that have been implemented in Germany, with a total storage capacity of 620 MWh (as of 2019). However, with the increase of large-scale grid integrated battery storage implementations, there are more available grid-stability reserves and the German reserve market is currently experiencing fewer values/payments in exchange for such reserve capacities.

- A few new business cases of aggregating home battery storage as a VPP have emerged in the German market, such as Sonnen. They are using aggregated home battery storage as an electricity supplier's tool, such as an imbalancing control measure or a balancing demand reserve in the wholesale market. The use of aggregated home battery storage for grid-integrated use in the active business case is hardly found in Germany yet.
- In Germany, a few major automobile manufacturers are working with industrial waste disposal companies in EV battery recycling pilot projects and they have started the discussion on EV battery recycling in 2030, when thousands of tons of wasted EV batteries will be waiting for recycling. In Japan, there has been practically only one BEV model in the market (Nissan Leaf) for more than a decade and the accumulated batteries from hybrid cars have been quietly disposed by either a car dealer or an industrial recycling specialist. Automobile manufacturers and the government have slowly started the discussions in a newly established "Used EV battery evaluation Council".
- It is still early to forecast the EV battery recycling business cases development, but experiences from Germany's EV battery recycling pilot projects indicate that the automobile manufactures may play major roles in the EV battery recycling business chains.

**C) Two countries share the perspectives/expectations, and Japan is ahead of Germany in implementation**

- In Japan, the deployment of commercial/industrial battery storage has progressed as much as accumulated deployment had reached 0.45 GWh at the end of 2019, and the Japanese government has developed the further deployment increase roadmap in commercial/industrial battery storage toward 2030 with 2.4 GWh target. Germany has slow progress in the deployment of commercial/industrial battery storage.
- In general, the development pathways for the installation and deployment of HSS and ISS in Japan are more defined than in Germany.
- Initial experiences from Japan's smaller distributed resources aggregation VPP project indicate that the commercial/industrial battery storage may have a high potential in an aggregated VPP business as long as there is a comfortably available reserve in the battery storage, which is not always the case in every industrial battery storage.

**D) Two countries share the perspectives/expectations, but there are differences in policy priorities/implementations**

- Securing the production capacity of EV storage batteries, especially lithium-ion batteries, by 2030 has been recognized as a task by both Germany and Japan, although the Japanese government and major Japanese manufacturers are siting new battery technologies other than lithium-ion. There is a strong position of the Japanese government that the battery storage policy does not limit to securing LIBs raw materials and the recycling of a LIBs.

- There is a general expectation on the EV battery evaluation standard and the battery performance measurement standard, but such an area is under severe technologies competition among car manufactures. In Europe, a draft amendment to the Storage Battery Directive has been published in late 2020, including life-cycle $CO_2$ footprints, environment labelling systems, and manufacturers' recycling obligations.
- BEVs sales are rapidly increasing in Germany exceeding 20 % of new car sales in 2020, and in 2021. The European Commission has proposed to ban the sale of new internal combustion engine vehicles, including PHEVs and hybrids, by 2035 (July 2021), and BEV sales and manufacturing are expected to increase sharply in European countries. On the other hand, Japan's share of new BEV vehicle sales in 2020 is only 0.6 %. In the new Green Growth Strategy (published in June 2021), Mobility/Battery is one of the 14 strategic growth fields and it sets a goal of 100 % electrified new car (passenger vehicles) sales by 2035 at the latest. The Japanese government is fully aware that the spread of BEVs in Japan is much slower than that in Europe and China. The Japanese government has considered the electricity source mixture transition period and also economic impact on the automobile industry, and the Japanese government maintains the position to consider electrified vehicles, not limited to BEVs, but including hybrid cars.
- In Germany, experts in energy systems are starting to look at the increasing BEV charging load effects on the local power grid, particularly at substation level. There is an expectation that EV batteries may contribute to the electricity demand-supply balancing and the grid stabilization reserve, but experts advise that the BEV's first contribution to the power grid is the flexible management of BEV charging load, avoiding the excessive stresses in the power grid operation and the investment that would be needed to strengthen the grid. The key considerations in the BEV charging load management are the "time" and "location" charging considerations, like promoting charging BEVs when there is plenty of solar/wind power generation and the careful development of public charging infrastructures considering the power grid capacity and the BEV users commuting routes.

  In Japan, one of the demonstration projects conducted a charging behavior change by introducing the time-dependent electricity rate, leading the BEV charging time during solar power generation peak hours, and the demonstration successfully lead BEV users to charge during lower rate hours. However, the charging stations deployment target in the Green Growth Strategy is the number of public charging stations by 2030, and little is considered with the charging load management or optimum charging infrastructures with power grid capacities.
- Regarding the re-use of EV batteries, initial pilot project scopes are different between Germany and Japan. In Germany, projects are trying to build larger stationary battery storages, LSS or ISS, while Japan's Nissan and FOR-R are trying to use in smaller applications, such as a less-demanding mobility and a backup battery of rail-crossing bars and street lights. The smaller application by Nissan and FOR-R seems challenging when many German

and Japanese experts have indicated that secondary use for smaller batteries may be difficult due to the variations of remaining capacities. In both countries, the reuse/recycling projects are still in progress until the used EV batteries quantity grows. Even Nissan, one of the first BEV manufacturers, can collect the first generation Leaf as much as 2,000 and that number does not match with active reuse/recycling business. It is also worth noting on the comment by FOR-R CEO that the evaluation of used EV battery is important for BEV manufactures in the sense of better residual valuation of upcoming new BEV models.

# 5 Conclusions and further research needs

Toward the realization of net-zero carbon targets, the increase of renewable power sources and the decrease of fossil-fuel power generation will require substituting flexibility measures to balance supply and demand, and to provide a grid stability reserve. Battery storage, including the grid-integrated large-scale battery storage (LSS), the home/commercial/industrial stationary battery storage (HSS/ISS) and the BEV battery storage (BEV) is expected to contribute significantly to this task.

We have conducted wide research and study on the potential, business models, and policy measures in Germany and Japan. In addition to the above use cases of batteries, this covered the possibilities for a 'second life' of BEV batteries in other applications and at the needs and options for recycling of batteries that have reached the end of their life. The following chapter will summarize the learnings from the study and investigate further research/study needs.

## 5.1 Conclusions

We have studied three types of battery storage systems: Grid-integrated battery storage (LSS), Home and Commercial/Industrial battery storage (HSS/ISS), and BEV battery storage. Power utilities and suppliers install LSS for power supply and demand balancing as well as the power grid stability. HSS and ISS are installed by the users for their own merits, and the same is the case for BEV. The potential and the future need for utilizing HSS/ISS and BEV batteries for the market flexibility and power grid stability is well recognized, but the current examples of such uses are limited.

Germany is ahead of Japan with the installation of LSS as much as 620 MWh/460 MW by 68 units. Germany's renewable generation supply in 2020 has exceeded 42 %, while Japan's renewable generation supply was 21 % in 2020. Germany's fast renewable supply growth may require LSS for the grid stability reserve. With these increasing LSS and other flexibility capacities as well as a better function of the intraday market, Germany is experiencing a decline in the grid-stability reserve market price. We are not sure whether the price decline is temporary, or the price decline will continue, while it is expected that the balancing reserve capacity need will continue to increase along with the solar/wind power supply increase.

HSS and ISS installation are increasing with the pursuit of users' own merits. With HSS, both German and Japanese users are in pursuit of maximum use of roof-top PV power generation, meaning the reduced purchase of electricity from the grid. With ISS, users intend to use battery power during the demand peak time to avoid over-payment of the demand charge throughout the year. Also, ISS are frequently used as backup power supply in industry processes.

In Japan, METI (Ministry of Economy, Trade, and Industry) and the HSS/ISS market players jointly worked to set the cost reduction target toward 2030. The study by METI did not include the possible merit of grid-stability values or the supply-demand balancing values.

The concept of aggregating many HSS and ISS and utilizing them like a virtual power plant (VPP) is widely recognized both in Germany and Japan. In Japan, METI has been conduction a demonstration project on VPP (Project ERAB: Energy Resources Aggregation Business) focusing on communication and remote-control technologies with many types of distributed resources. In Germany, there is a precedent case where Sonnen, an electric power supplier, is distributing Sonnen-produced home battery storage to customers and uses an aggregated supply capacity in the wholesale market as well as the demand-supply balancing measure. Such a case is in the early stage and not at the level of large commercial-scale deployment. The grid stability reserve capacity in Germany is predominantly supplied from increasing LSS, except for a few demonstration projects with HSS and BEVs.

There is a difference in the situation between Japan and Germany regarding electric vehicle deployment, which is the prerequisite for the utilization of BEV batteries for grid stability. BEV sales are growing rapidly in Germany and Europe. If Germany reaches its new target of 15 million BEVs on the road in 2030, the total storage capacity of all passenger BEVs in Germany may amount to 1.575 TWh and 15 GW by then. We want to highlight the insight from a study by Hildermeier et al. (2019) on the BEV market penetration and the power-grid effects. Hildermeier suggests that the first best contribution of BEV to the power grid is to manage the charging time and locations so that the BEV charging demands may not excessively give stresses to the local grid operation. This first contribution should be understood and recognized by involved players, including policymakers, before we also study BEV battery discharging (vehicle-to-grid) to enhance grid stability.

Regarding the reuse of BEV batteries, there are a few programs in Japan, with fewer electricity demand cases, such as forklifts, street lights, emergency power sources in shelters. However, literature reviews and interviews with experts, both in Germany and Japan, suggest the BEV batteries re-use in a smaller size, such as a Home Battery Storage, can be very challenging, due to the battery’s widely varying remaining capacity. Germany has conducted some large-scale BEV battery recycling demonstration projects, mostly conducted by auto-manufactures and industrial waste disposal companies. Olssen et al.'s study (2018), which is focusing on the business models of BEV battery recycling, suggests that the involvement of automobile manufacturers will be a major factor in BEV battery recycling and reuse.

Regarding regulatory frameworks to improve the conditions for using LSS, HSS/ISS and BEVs as a flexibility resource, we found:

- It is necessary to remove any double charging with levies, fees, or taxes of electricity during storage charging and discharging for feed-back to grid, starting from a clear definition of storage as an own element of the electricity system. In the EU, this has been decided in the last revision of the electricity market directive but needs to be implemented in Germany. Removing any double charging may now happen soon with the 2022 revision of the renewable energy law (EEG). In Japan, the Strategic Policy Committee addressed the clarification of “LSS-Storage” business in the electricity power system. The Committee suggests the “LSS-Storage” can be treated as “Generation” with safety responsibility consideratons. The Committee also suggests that the “LSS-Storage” should bear the transportation cost in discharge-portion and the storage-loss portion.

- As a technical precondition, stationary battery installations as well as BEVs and charging points will need smart meters and submeters. Although submeters may not need the full data protection and security, cost may still be a barrier for deployment especially in small-scale storage, such as HSS and BEV charging (both private and public). Therefore, financial incentives for investment (grants, subsidized loans) are likely needed for some time. Although Japan is more advanced than Germany in the roll-out of smart meters, and technical demonstrations are ongoing in both countries, both Germany and Japan will need to develop the policy support and framework for mass-scale business cases further.
- In addition, smart pricing will also be needed to make flexible charging/discharging financially attractive, such as time of use tariffs enabled through the smart (sub-)metering. Both countries still have to stimulate the wider use of such incentives. The creation of a balancing reserve market in Germany has been very useful in this respect, and its ongoing introduction in Japan is expected to improve the framework for flexible use of batteries in similar ways.

Several steps will also be needed for improving the regulatory framework for 'second life' and recycling, including clear and operable standards for assessing the remaining capacity and quality of used batteries. We found that the industry and the policy makers are carefully working on the battery health assessment standard with understanding the battery management is in the highly competitive field in the industry. Germany may need to follow the Storage Battery Directive after approval of the European Commission proposal for amendment. Japan is rather taking a soft approach with industrial standard gudelines agreed by a voluntary working group.

## 5.2 Future study/research needs on technology, policy intervention and business development

We started this study to try to understand the current situations, potentials, new business models, and associated policies with the possible contribution of distributed battery storage to the grid stability capacity or the power supply-demand balancing measures. There are a few demonstration projects and a precedent case with using home/commercial/industrial battery storages to a demand-supply balancing and a grid stability reserve use, but they are not in the stage of being commercially ready to deploy. There are studies on the use of such distributed battery storage to grid stability and the demand-supply balancing, and we want to highlight one of the suggestions by Hildermeier et al. (2019). Hildermeier et al. suggest that the first best contribution of BEV to the power grid is to manage the charging time and locations so that the BEV charging demands may not excessively give stresses to the grid operation. We understand that EV charging infrastructure development is the essential twin of successful EV market development. Many policies target numbers of public charging stations, but Hildermeier's study points out the importance of information/data readiness of how/when/where BEV charging demands will affect power grid capacities and operations.

According to the German charging infrastructure masterplan from 2019, the total BEV charging demand in 2030 can amount to 1/8 of the total electricity demand when the BEV deployment exceeds 10 million. With the new government aim of 15 million BEVs in 2030, the demand is expected to increase even further. Therefore, it is important to note the following: When BEVs charge should reflect the renewable energy generation, where BEVs charge should reflect the power grid system capacity locations, thus the charging infrastructure should be developed accordingly with the consideration of BEV users' accessibility. It is important to recognize that the BEV charging system and behaviour should consider "time" and "location".

To develop the "time" and "location" conscious BEV charging infrastructures, data provision of power supply and the power grid capacity is essential. Such data can be highly useful for the development of time-dependent charging prices, a forecast of power demand-supply balancing, and a forecast of the grid stability reserve demand.

Hildermeier et al. also make many recommendations on the BEV charging infrastructure development. Hildermeier suggests the importance of "smart charging technologies" and "smart charging infrastructures". The former includes a smart user interface, such as a smart application guiding optimum charging behaviour without hustling too much information on the dynamic price and the payment. The latter includes a building code update to mandate EV charging capacities, unconventional charging spots with street light poles, and road parking spaces. There is a need for further studies on these smart charging technologies and smart charging infrastructures. For example, future research could deepen the topic of BEV charging management with a comparison between Japan and Germany when it comes to framework conditions, infrastructure planning and business cases.

To conclude, the potential of BEVs and also HSS and ISS for market balancing and grid stabilization may be enormous, but whether it is cost-effective in relation to other flexibility, will depend on the extra cost of controls for their flexible use for grid/system purposes, and the economic environment of markets and time-of-use or other smart power prices.

We may assume that in the future, BEV sales are going to increase even further, while it is still unsure if this will continue to be the case for HSS with PV, and also for ISS for private cost optimization with/without PV. If so, the extra cost of flexibility will only be the cost of control and users' opportunity. Those two factors are still to be further researched and calculated, to better understand the size of the potential of these systems for market balancing and grid stabilization that may eventually become reality in the future to support decarbonization of power systems.

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# 付録４. 2050 年に向けた長期シナリオ分析

German Japanese Energy Transition Council

www.gjetc.org

# GJETC 2021 study on Long-term scenario analyses up to 2050

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# Content

# Tables



# Figures

# 1. Introduction

## 1.1 Background

The main outcome of the COP 26 in Glasgow (2021), to keep 1.5 degrees within reach, remains a huge challenge even for all countries, which have committed themselves to a rapid and substantial reduction of greenhouse gas emissions in the Paris Agreement (2015). In its latest report (March 2022), the Intergovernmental Panel on Climate Change (IPCC) emphasized the urgency of more ambitious action to fight against ongoing climate change that poses a dangerous threat to the well-being of humanity. The recent floods, typhoons and other extreme weather events that occurred in Germany and Japan indicate that the current climate change trends will cause immense economic damages to national economies also in temperate latitudes. Geopolitical consequences of fossil fuel dependency emerging from the Russian aggression against Ukraine add another urgent objective for the phase-out of fossil fuels, in addition to climate change mitigation. Against this background, climate protection and achieving climate neutrality as quickly as possible are highest priority challenges to human kind, and they stand under extreme time pressure. On the one hand, as leading industrialized countries, both Germany and Japan, are facing a particular responsibility and challenge to reduce greenhouse gas emissions. On the other hand, both countries can provide advanced economic, technological and societal capacities and innovations to meet these challenges. Thus, they can benefit from the economic and risk-minimizing opportunities that the transformation to net zero implies. The recent changes of governments in both countries have had remarkable consequences for Germany and Japan's climate mitigation policies. While maintaining the energy policy objectives of energy security, economic efficiency and environmental sustainability, the new governments increased their ambition level and, for example, raised the targets for $CO_2$ reduction, for expanding renewable energies and for fostering energy efficiency significantly, albeit the approaches differ.

In both countries, scenario studies are important instruments to provide scientifically based policy advice on complex matters such as the energy transition and to support the governments in finding feasible and viable pathways to climate neutrality. However, methods, model assumptions, choice of technologies, policy priorities and the degree of policy integration differ between the two countries. For example, there are different assumptions whether to rely on energy technology options only, or to include resource efficiency and Circular Economy (CE) strategies, as well as behaviour and lifestyle changes. Thus, different approaches and pathways to net zero are possible.

## 1.2 Rationale and objectives of the study

In 2017, the GJETC had conducted a first study on the "Energy transition as a central building block of a future industrial policy". In a comprehensive meta-analysis, a German-Japanese study team had examined a wide range of strategic options for the energy transition as well as the associated strengths and weaknesses of the energy transition strategies of both countries. In 2021, the GJETC decided on this follow-up study and to update the findings, albeit on a much smaller scale. The study objective was to identify current climate neutrality scenarios for Germany and Japan and to compare them based on two guiding questions: (1) What strategic technological options are available to reach net zero?, and (2) What lessons can be learned from the analyzed decarbonization strategies that might be transferable?

The first step consisted in identifying the range of already existing research based, long-term scenarios, including those that go beyond current official national targets. Assessment criteria for the selection of relevant studies and for the comparison of the scenarios were established. In the next step, 5 Japanese and 4 German scenario studies were selected and analyzed, comparing assumptions and results. The scenarios cover a range of long-term strategic options for both Germany and Japan. Moreover, gaps in the existing scenarios were also identified. Finally, conclusions were drawn, including potential strategies to address the shortcomings.

## 2. Update of assessment criteria and selection of studies

Authors: Institute of Energy Economics, Japan and Wuppertal Institute for Climate, Environment and Energy

Based on a literature screening a range of relevant scenario studies for Japan and Germany was identified. These studies describe the medium to long-term effects of a transition and the associated economic implications towards climate neutrality.

Following the decision of the Japanese government to reach carbon neutrality by 2050 (October 2020), only scenarios considering carbon neutrality were included. Considering Germany's more ambitious target to reach climate neutrality as early as 2045, a number of scenario studies had already been published in autumn 2021. Accordingly, for the analysis in this report, the selection of scenarios for Germany was based on the following criteria:

- publishing date, target year of climate neutrality 2045/2050
- quantitative details for energy demand and supply side for at least 2030
- including aspects of economic feasibility
- representing a broad range of assumptions and approaches

Applying these criteria, the scenarios shown in table 2 were selected from a more comprehensive list of relevant scenario studies.

For the Japanese side, there were chosen consultants and an institute (table 1.) that shared their own scenario analysis with the Strategic Policy Committee, in order to discuss the direction of Japan's energy policy, aside from the governmental strategies. Against this background this study focuses on scenarios conducted by the following organizations:

*Table 1: Japan: Organizations that shared their scenario analysis up to 2050*

| Organization | Publication | Title | Organization characteristics |
|---|---|---|---|
| 1. The Research Institute of Innovative Technology for the Earth (RITE) | 2021 | Scenario analysis about carbon neutrality in 2050 (Interim report) | Founded by the GOJ to promote innovative environmental technologies worldwide. |
| 2. The National Institute for Environmental Studies (NIES) | 2021 | Analysis about scenarios toward decarbonization by 2050 | A central institute for environmental research since 1970. |
| 3. Renewable Energy Institute (REI) | 2021 | Energy mix supporting decarbonization in 2050 in Japan | Non-profit institute, founded by a company-owner to promote renewable energy. |
| 4. Deloitte Tohmatsu Consulting | 2021 | Scenario analysis for carbon neutrality society | One of the Big Four accounting firms. |
| 5. The Institute of Energy Economics, Japan (IEEJ) | 2021 | Model analysis for carbon neutrality in 2050 | Founded by the GOJ of the research institute on energy and environmental policies. |

For the German side, we attempted to map the most recent scenarios, focusing on the target year 2045 and highlighting the technical and economic feasibility, while also presenting a certain bandwidth. Hence, (innovative) approaches also played a role, such as considering the effects of a circular economy and behavioral changes. Against this background the following scenarios were selected. This includes the UBA study, although it focuses on 2050, since it addresses integration aspects of climate and resource strategies that appeared to be ground-breaking and are not covered by the other studies.

*Table 2: Germany: Overview and selection of long-term scenarios up to 2045*

| Organization | Publi-cation | Title | Organization characteristics |
|---|---|---|---|
| 1. Agora Energiewende, Agora Verkehrswende, Stiftung Klimaneutralität (Agora 2045) | 2021 | Climate Neutral Germany 2045 - How Germany can achieve its climate targets before 2050. | The think tank search for compromise solutions that can gain majority support in the restructuring of the electricity sector within the energy transition. Important player in the field of energy policy consultancy. |
| 2. German Energy Agency (Dena 2045) | 2021 | dena lead study – The dawn of climate neutrality. | A federally owned German company that provides services to shape and implement the German government's energy and climate policy goals on energy transition and climate protection. |
| 3. Federation of German industries (BDI 2045) | 2021 | Climate Paths 2.0 – A program for Climate and Germany´s Future Development. | Leading association of German industry and industry-related service providers, speaking for 40 industry associations and more than 100,000 companies. |
| 4. German Federal Environment Agency (UBA, GreenSupreme 2050) | 2020 | Transformation process to a greenhouse gas neutral and resource-efficient Germany – GreenSupreme | Central environmental authority of the Federal Republic of Germany and part of the portfolio of the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection. Primary task: the scientific support of the federal government, the enforcement of environmental laws and the provision of information to the public on environmental protection based on independent research. |

# 3. Climate policy and energy transition targets for 2045/2050

Authors: Institute of Energy Economics, Japan and Wuppertal Institute for Climate, Environment and Energy

## 3.1 Japan (2050)

In 2020, the Japanese government declared its objective to reduce greenhouse gas emissions (GHG) by 46% by 2030 over 2013 levels, and to reach net-zero by 2050. GHG emissions in 2018 amounted to 1.06 billion tons including emissions from the power sector (440 million tons), buildings (110 million tons), industry (300 million tons), and transport sector (200 million tons). Apparently emissions from the power sector are responsible for a large portion of total emissions.

In Oct 2021, the *6th Strategic Energy Plan* was published by the Japanese government. The plan describes the major direction of the strategy on energy demand and supply for the timeframe 2030 until 2050. Japan's energy use accounts for over 80% of greenhouse gas emissions and thus the plan presents key information on how to reduce the GHG emissions in the energy sector: Based on assumptions related to the expected renewable energy installations or demand, the plan shows a concrete energy supply/demand balance and power sector energy mix in 2030 while also presenting related policies and measures. The 6th Strategic Energy Plan describes that apart from utilizing renewable and nuclear energy, technology innovation for hydrogen/ammonia power plant and CCUS should also be pursued. As for the non-power sectors like transportation and buildings, electrification should be expanded.

Thus, the Japanese government considers various options to realize carbon neutrality by 2050 while also considering the compatibility with a stable energy supply and reducing the national economic burden. On the other hand, the plan does not show a concrete scenario for 2050, but only describes the intended broad direction of Japan's energy policy towards

2050. This is due to the fact that an outlook on 2050 depends on several factors such as technology innovation or future energy demand, both remaining uncertain.

## 3.2 Germany (2045/2050)

In April 2021, Germany experienced a ground-breaking step in its climate protection legislation when the Federal Constitutional Court (German: Bundesverfassungsgericht, BVerfG) ruled that the German state was obliged to prevent any future disproportionate restrictions in the fundamental liberties of today's young generation (Constitutional Court 2021, 1 BvR 2656/18) and by that forced the government to take immediate action. Thereafter, the targets of the climate law from 2016 were tightened as to achieve climate neutrality no later than 2045 with interim targets for greenhouse gas reductions until 2030 (-65% compared to 1990) and 2040 (-88% compared to 1990). In addition, the sector targets for the energy, industry, transport and building sectors until 2030 have also been tightened (see table 3) and will be further specified in 2024 and 2032. It should be noted that the sector targets are binding for the responsible ministries and a rigorous enforcement mechanism was decided in case that the reduction trajectories are missed.

*Table 3: Annual emission budgets according to sectors [Million t $CO_2eq$]*

| **Annual emission budgets** in millions t $CO_{2eq}$ | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Energy** | 280 | * | 257 | * | * | * | * | * | * | * | 108 |
| **Industry** | 186 | 182 | 177 | 172 | 165 | 157 | 149 | 140 | 132 | 125 | 118 |
| **Buildings** | 118 | 113 | 108 | 102 | 97 | 92 | 87 | 82 | 77 | 72 | 67 |
| **Transport** | 150 | 145 | 139 | 134 | 128 | 123 | 117 | 112 | 105 | 96 | 85 |
| **Agriculture** | 70 | 68 | 67 | 66 | 65 | 63 | 62 | 61 | 59 | 57 | 56 |
| **Waste and others** | 9 | 9 | 8 | 8 | 7 | 7 | 6 | 6 | 5 | 5 | 4 |

Source: Climate Protection Law 2021

Details of the climate protection law shall be improved in accordance with EU legislation. The same holds true for the national $CO_2$ pricing instrument that, from 2024 on, shall be adjusted according to an evaluation of the expected EU regulation so as to improve coordination of national measures with European strategies (Climate Protection Law 2021, DS 19/30230).

In general, as a Member State of the European Union, Germany's energy and climate policy is deeply influenced by the regulations of the EU. With the European Green Deal, the EU proclaimed that it will become the first climate-neutral continent by 2050 (The European Green Deal 2021, COM (2019) 640 final). This general target has been specified in the *fit for 55-package* aiming at a GHG emission reduction of 55% by 2030 and foreseeing a number of legislative proposals with which the EU seeks to encourage and, in some parts, require Member States to tackle global warming (ibid).

Following the German parliamentary elections in September 2021, a new government consisting of the Social Democratic Party, the Green Party and the Free Democratic Party came into office. Their coalition treaty proclaims a highly ambitious acceleration of green electrification and aims at 80% renewable energy coverage of gross power demand by 2030 while 'ideally' phasing-out coal in that same year in addition to the nuclear phase-out in 2022. To secure these goals in all federal states, a challenging target was set to reserve 2% of the total area of each federal state for onshore wind power. Other noteworthy plans include the highly ambitious increase of renewables in heating buildings (65% up to 2025) as well as the goal to achieve a total of 15 million all-electric vehicles by 2030. In the same year 10 GW of domestic electrolysers for hydrogen production shall be established to be fed by offshore wind power and supported by a high imported share of green hydrogen. With the exemption of some proposed measures for the building sector, energy efficiency does not play a very prominent role in the coalition treaty but will continue to be part of the implementation of Germany's Climate Protection Law.

# 4. Analysis of the Japanese scenarios

Author: The Institute of Energy Economics, Japan

## 4.1 Methods used and key assumptions

### 4.1.1 Model comparison

In Japanese scenarios, almost all scenarios use models to minimize total energy system costs including capital costs and variable costs (among others). It should be noted that although the basic approach of each model is similar, the definitions of costs can be different in each model.

These models must be understood not as forecasts, but as back-casting models assuming carbon neutrality by 2050 as a model restriction. Hence, these scenarios do not necessary assure that carbon neutrality is technically or economically feasible but draw a picture or indicate net zero issues under several conditions.

*Table 4: Model comparison*

| | RITE | NIES | REI | Deloitte | IEEJ |
|---|---|---|---|---|---|
| **Model** | Dynamic New Earth 21+ model | Integrated model (general equilibrium/ bottom-up/ generation mix) | LUT Energy System Transition modelling | IEA TIMES Model | IEEJ-NE model |
| **Objective** | Minimizing total energy system costs (capital cost, variable cost, etc...)* | | | | |
| **Temporal resolution** | 1 hour | 1 hour | 1 hour | 4 hours per 4 seasons | 1 hour |
| **Spatial resolution** | 1 node | 10 nodes | 9 nodes | 351 nodes | 5 nodes |

### 4.1.2 Macro framework

Almost all models' macro frameworks include population, GDP, service demand, etc. (table 5). These assumptions may affect the final energy consumption. However, the difference of assumptions among the models is small. As for fuel prices, many models refer to the World Energy Outlook 2020 (WEO 2020) published by the International Energy Agency (IEA). Hence, assumed fuel prices are also similar among the models.

*Table 5: Macro framework in model assumptions*

| | RITE | NIES | REI | Deloitte | IEEJ | Min | Max |
|---|---|---|---|---|---|---|---|
| **Population in 2050** [million] | 96-122 | 101.9 | 101.4 | n.a. | n.a. | 96 | 101.9 |
| **Households in 2050** [million] | n.a. | 47 | n.a. | n.a. | 52 | 47 | 52 |
| **GDP growth rate** [%/year] | -0.1 ~ 1.2 | 0.5 | n.a. | n.a. | 1 | -0.1 | 1 |
| **Crude steel production in 2050** [million t] | 73-111 | 85.7 | n.a. | n.a. | 119.7 | 73 | 119.7 |
| **Cement production in 2050** [million t] | 31-75 | 60.4 | n.a. | n.a. | 43.4 | 31 | 75 |
| **Ethylene production 2050** [million t] | n.a. | 5.4 | n.a. | n.a. | 4.4 | 4.4 | 5.4 |
| **Paper production in 2050** [Mt] | n.a. | 23.5 | n.a. | n.a. | 21.2 | 21.2 | 23.5 |
| **Passanger in 2050** [Trillion p-km] | 0.64-0.82 | 1.18 | n.a. | n.a. | 1.23 | 0.64 | 1.23 |
| **Freight in 2050** [Billion km] | n.a. | 419 | n.a. | n.a. | 457 | 419 | 457 |
| **Coal** (2040)[USD/t] | 54 | 61 WEO2020 | 0.89 JPY/kWh | 61 WEO2020 | 61 WEO2020 | 54 | 61 |
| **Crude oil (2040)** [USD/barrel] | 76 | 53 WEO2020 | 3.45 JPY/kWh | 53 WEO2020 | 53 WEO2020 | 53 | 76 |

**) 115 JPY = 1 USD, 0.88 EUR = 1 USD; n.a. = not available

### 4.1.2 Renewable energy capital cost

All models use capital costs of renewable energies as a parameter. However, capital costs are significantly different depending on whether domestic or international costs are assumed.

As for PV systems, NIES inserts the smallest capital costs among the models. The capital costs are international costs estimated by IRENA 2019. REI also uses international costs estimated by ETIP-PV[1] and Vartiainen 2019. The cost developments are estimated by a learning curve with a learning rate of 40%, which is larger than typical learning rates (E.S. Rubin et al. 2015). Deloitte estimates the highest capital costs among all models. The capital costs referred to mirror the current costs estimated by the Japanese cost working group. IEEJ inserts capital costs by assuming a learning rate of 21% for PV modules and a learning rate of 15% for domestic balance of system (BOS) costs including racking or wiring. RITE shows approximately 50-150 USD/MWh of LCOE in 2050 instead of capital costs. The range arises from the difference of irradiance in each area.

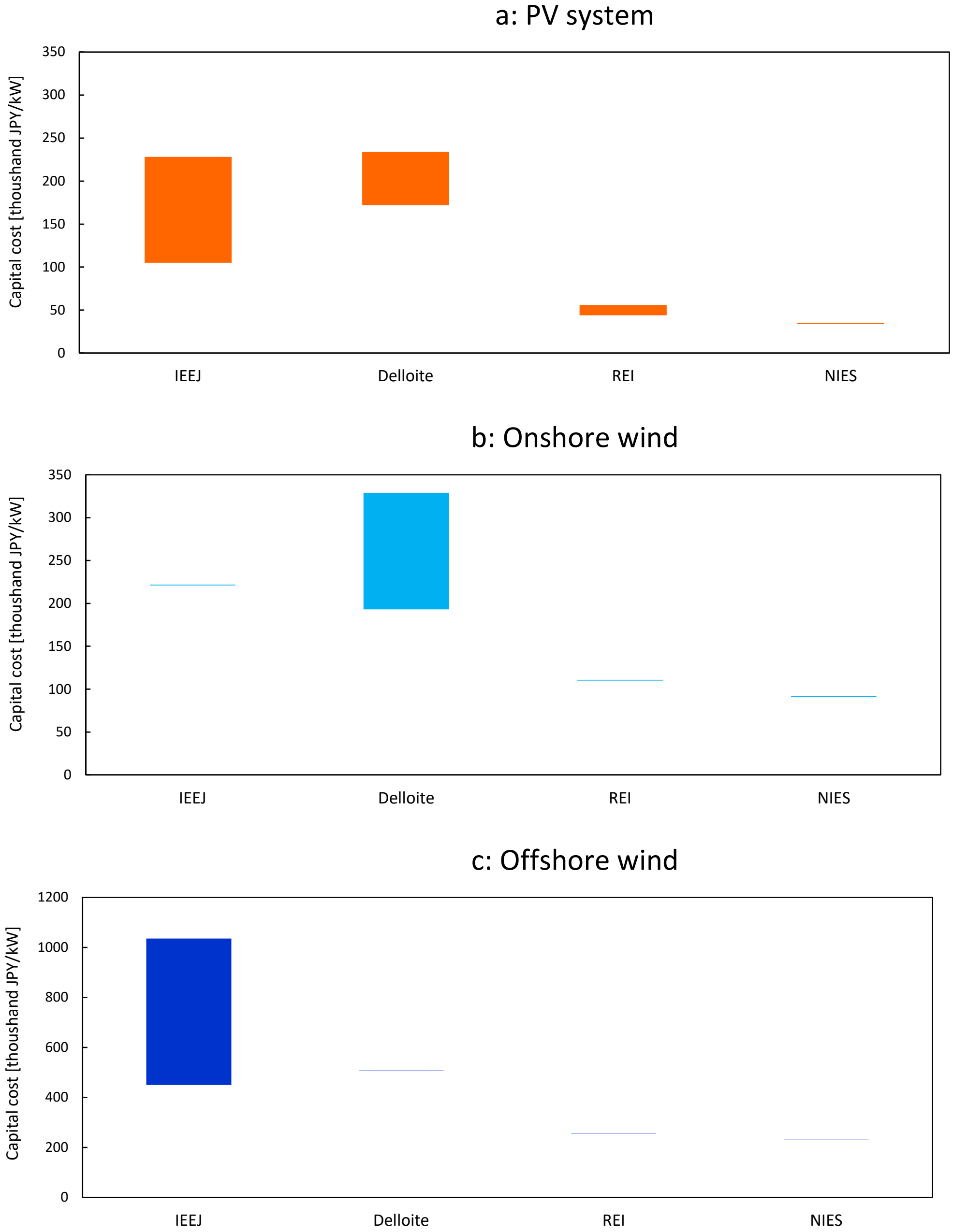
As for onshore and offshore wind systems, NIES uses the smallest capital costs among models. The capital costs are international costs estimated by IRENA 2019. REI also assumes international costs estimated by E3 for PRIMES[2] and EC. Deloitte refers to the highest capital costs among the models in line with the current domestic costs estimated by the Japanese cost working group 2021. IEEJ estimates capital costs by assuming a learning rate of 8% for wind turbine and a learning rate of 7% for domestic BOS costs. RITE shows approximately 70-180 USD/MWh of Levelized Cost of Electricity (LCOE).

Currently, there is a gap between international costs and domestic costs, both for PV systems and onshore wind energy systems, due to technical particularities related to typhoons or earthquakes that are reflected in the domestic costs. For example, PV systems must use stronger racking systems against strong wind. Moreover, the design of wind towers can be different from the wind tower installed in Europe because Japanese towers must be able to withstand earthquakes. Hence, technical particularities are challenges for the conversion of domestic costs into international costs.

[1] Concrete publication title was not shown.

[2] Concrete publication title was not shown.

*Figure 1: Assumed capital costs in 2050 [thousand JPY/kW]*




* 100 thousand JPY ≒ 77 EUR
* RITE shows LCOE(PV: approx. 50-150 USD/MWh, Wind: 70-180 USD/MWh) instead of capital cost.

### 4.1.3 Solar and wind energy potential

Since almost all Japanese contiguous land is covered by forest, the estimated solar and wind energy potential is a key factor to influence the energy mix. The assumed potentials of these energies are significantly different depending on the installation sites (such as farmland and forests), and on the rules for zoning of offshore wind. These assumed potentials make a big difference among the model results especially for the energy mix in 2050.

As for PV systems, REI assumes the highest potential (2,746 GW) by referring to the report by the Japanese Ministry of Environment (MoE) 2021. Due to this estimated massive potential, the large majority of it is assumed to be installed on farmland (2,365 GW). Due to the Japanese agricultural law, PV systems installed on farmland must ensure enough space between PV modules to ensure sufficient crop radiation. If the agricultural production is significantly reduced after installing a PV system, the permission of agricultural land conversion will be revoked.

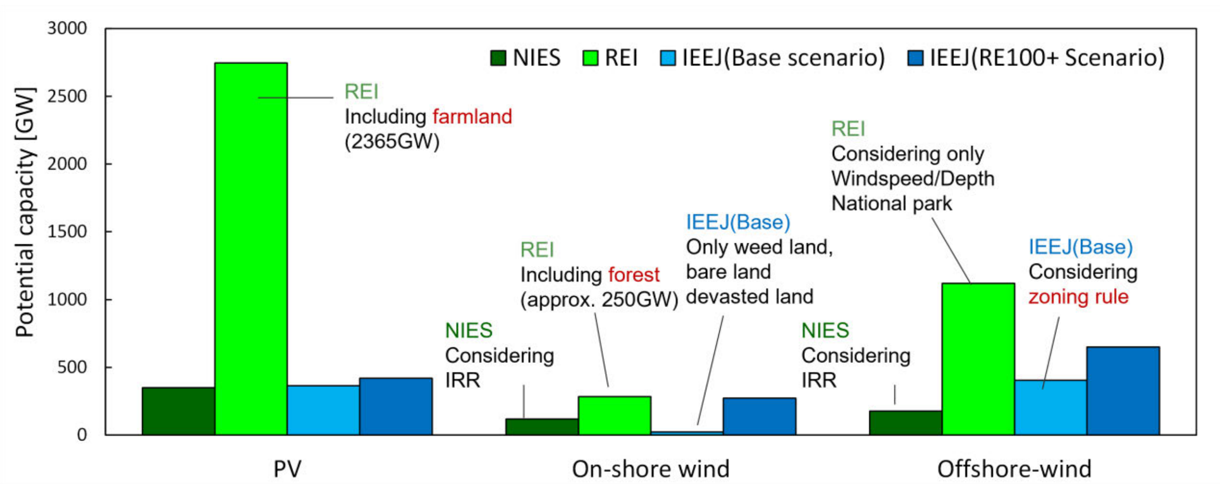
NIES and IEEJ assume a potential of approximately 360 GW for PV systems. This potential is assumed by installations on the roofs and walls of buildings and installations on weedland and devasted land. RITE sets an upper limit of generated electricity (750 TWh/yr.) instead of installed capacity.

As for on-shore wind energy systems, REI assumes the highest potential (285 GW) by referring to the report by the MoE 2021. However, most of these installations are assumed to be in the forest where the annual average wind speed is ≥ 5.5 m/s (approximately 250 GW). Currently, local governments tend to regulate installations in forests to conserve the local nature or environment. Excluding the potential installation areas which may cause a negative impact to the local environment such as forests, only 23 GW of on-shore wind energy is possible to be installed (Obane et al 2020). Following this fact, IEEJ assumes two potentials depending on whether local environments are considered (Base scenario), or not (RE100+ scenario).

NIES assumes a potential (118 GW) that takes into consideration not only technological and legal restrictions, but also economic restrictions by referring to the report of the MoE 2011. In the MoE report, the potential taking into consideration only technical and legal restrictions is 285 GW. If economic restrictions are further considered as well, the remaining potential is 118 GW. These potentials do not take into consideration local environments. RITE sets an upper limit of generated electricity (200 TWh/yr.) instead of installed capacity.

As for offshore wind energy systems, REI assumes the highest potential (1,120 GW) by referring to the report of the MoE 2021. The scenario assumes installations in all areas where the annual average wind speed is ≥ 6.5 m/s, the water depth exceeds 200 m, and the distance from shore is bigger than 30 km, while national parks are not included. NIES assumes the potential that considers economic restrictions in addition to the above-mentioned sea use restrictions (177 GW). However, offshore wind energy systems can currently be installed in areas (promoting zones) that are determined by zoning rules. For example, a promoting zone can be determined within the Japanese territorial waters (according to the international sea water jurisdiction within a radius of 22.2 km) by considering natural conditions, shipping routes, grid connection, among others. Accordingly, the base case of IEEJ assumes a potential of 405 GW by considering these zoning rules (Obane et al. 2021). However, this potential includes areas restricted by fishery rights or near the shore areas where the sea scape is possibly destroyed by a lot of turbines.

*Figure 2: Assumed solar and wind energy potential in 2050*



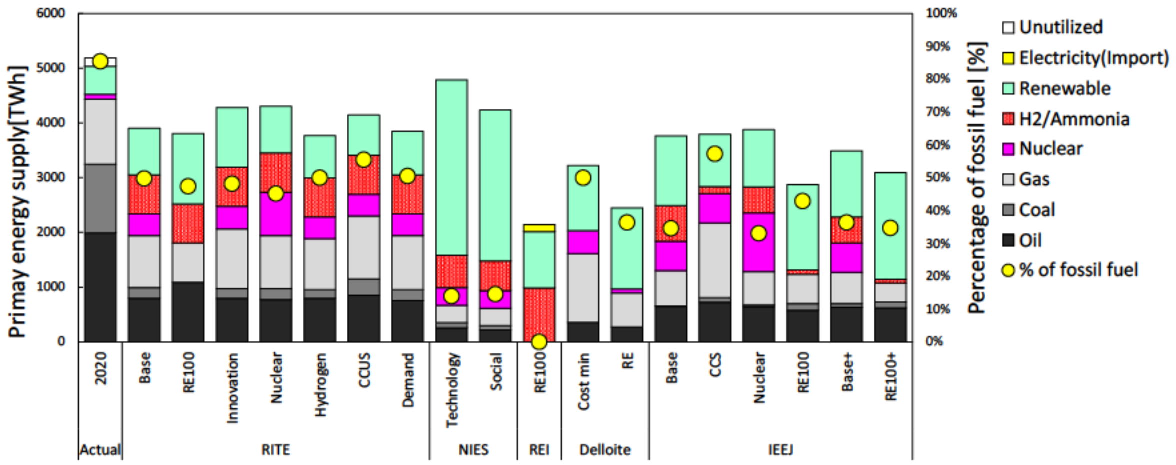
## 4.2. Key results

### 4.2.1 Primary energy supply in 2050

In 2020, the primary energy supply from fossil fuels accounted for 85%. Moreover, oil energy supply accounted for 38% of the total primary energy supply because oil was mainly used for transportation. On the other hand, all scenarios show that the primary energy supply from fossil fuels in 2050 will be significantly reduced as a result of cost optimization when carbon neutrality is assumed in back-casting models. Instead of this, renewable energy, hydrogen, ammonia, and nuclear are assumed to fill the gap for securing the primary energy supply.

The scenarios including the utilization of CSS, indicate higher percentages of fossil fuels, compared to the scenarios developed by NIES, where fossil fuels account for 14-15% of the total primary energy supply. Moreover, the scenarios including the utilization of renewable energy indicate smaller percentages of fossil fuels. REI shows a final energy supply instead of a primary energy supply. Although the definition is different from the other scenarios, REI's scenario shows that final energy supply from fossil fuels is reduced to zero by utilizing hydrogen.

*Figure 3: Primary energy supply in 2050 [TWh]*




* As for REI, final energy supply is referred to. Hence, the total energy supply is not necessarily consistent to the other results.

### 4.2.2 Electricity generation mix in 2050

In 2020, the percentage of generated electricity from renewable energy was 20%. In March 2022, only 10 of 60 nuclear power plants worked, and 24 out of 60 power plants are determined to be shut down. Although the percentage of electricity from renewables may be different among models, it is approximately 40-100%. Here, the RE100 scenarios (RITE, REI, IEEJ) intend to achieve nearly 100% renewable energy, according to the model calculations. However, the model results are not necessarily the most cost-effective. If the RE100 scenarios are excluded, the average percentage of renewable energy is 40%-70%.

The scenarios considering the use of nuclear energy estimate that existing nuclear power plants should be fully restarted. Moreover, many models show zero emission thermal power such as ammonia or CCS being utilized to cover the total electricity demand in 2050. Some scenarios, including the RE100 scenario, show an extremely high percentage (>90%) of renewable energies. However, it should be noted that renewable energies in these scenarios are assumed to be installed in restricted areas such as farmland or forests. For example, although the REI-scenario predicts a PV capacity of 524 GW, this capacity exceeds the potentials on buildings, weedland or devasted land (MoE 2021). In order to achieve this capacity, approximately 200 GW of the PV system capacities need to be installed on farmland. In this context, it is important to carefully consider the compatibility of the PV systems with the aforementioned restrictions related to the Japanese agriculture law (see chapter 4.1).

Moreover, achieving a capacity that exceeds 100 GW by onshore wind installations as assumed by many scenarios, requires onshore wind energy installations in forests.

Thus, although some scenarios show a high percentage of renewable energy, local environment or social acceptance must be carefully considered if a massive installation of renewable energy is planned according to these scenarios.

*Figure 4: Generated electricity in 2050 [TWh]*

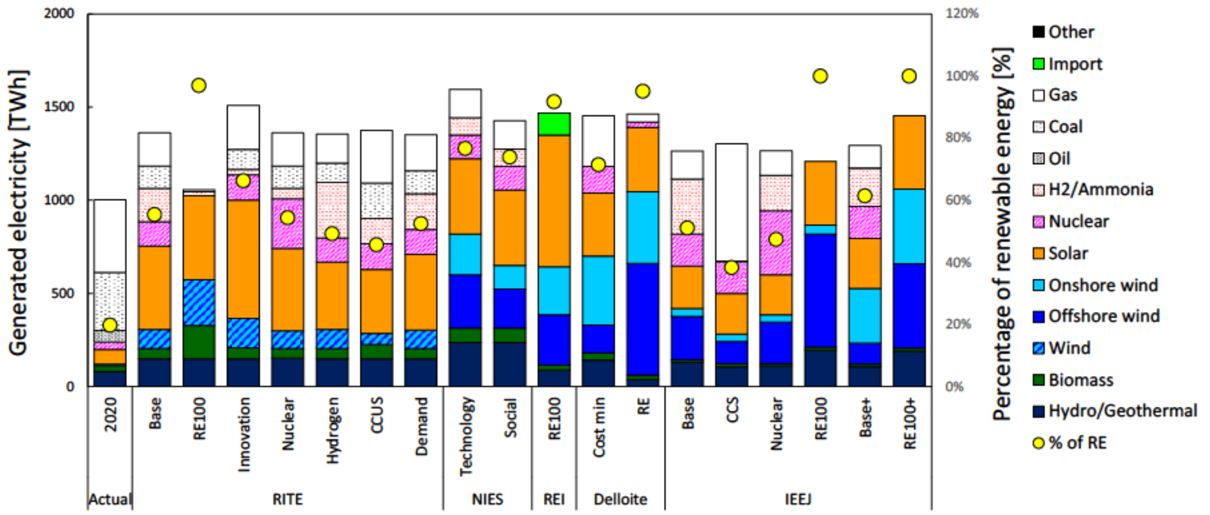
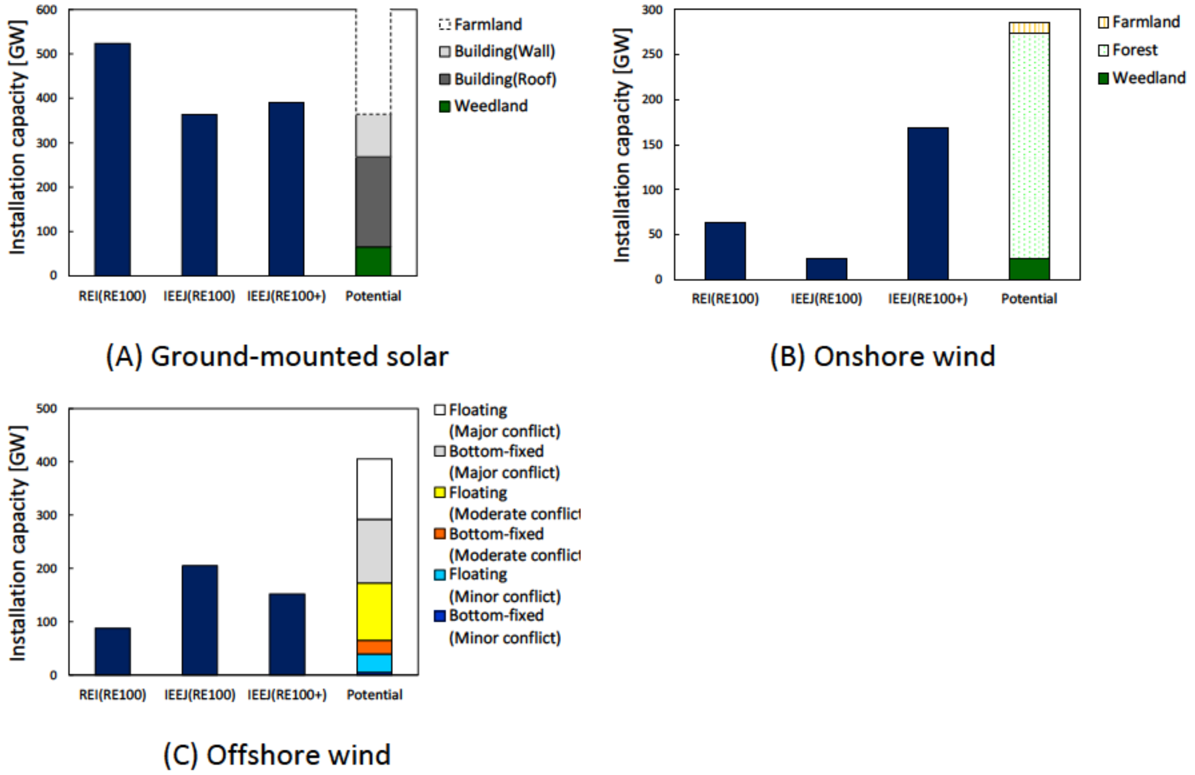



*Figure 5: Comparison of installed capacity with technical potential [GW]*



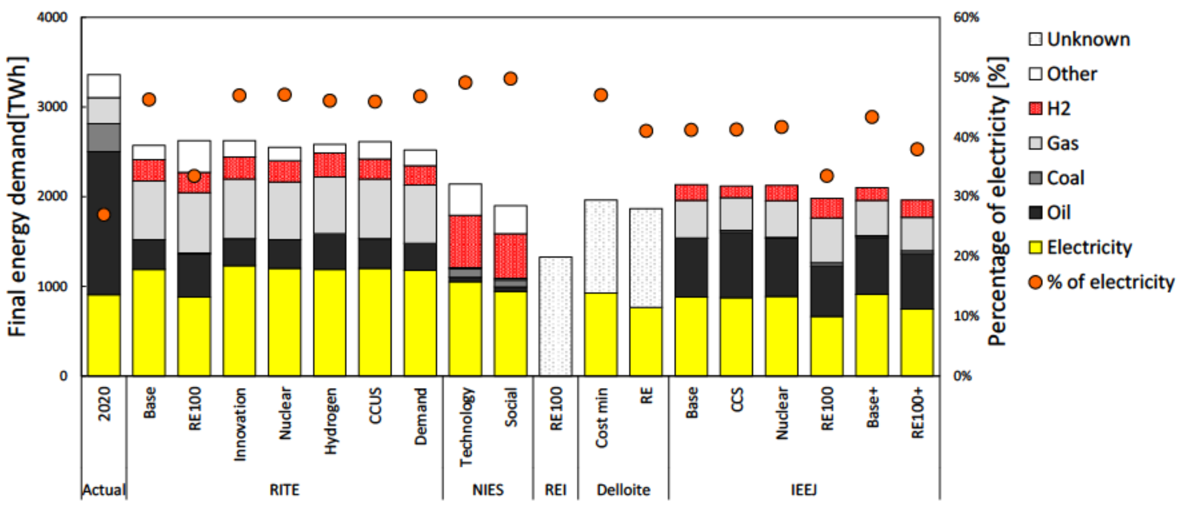

* Potential is referring to MoE 2021, Obane et al. 2021, Obane et al. 2020.

### 4.2.3 Final energy demand in 2050

The final energy demand in 2020 amounted to 3,361 TWh and the percentage of electricity accounted for 27%. Most of the current final energy demand is covered by fossil fuels. Many scenarios show that the final energy demand is reduced to approximately 3,000 TWh by 2050. This is mainly caused by the transition from oil to gas or hydrogen by 2050. Since the total final energy consumption will be reduced by 2050, the percentage of electricity will increase up to 40 – 50%. Although the percentage of electricity is higher, it should be noted that the absolute amount of final electricity demand is not necessarily increased.

Many scenarios show that the oil and gas demand will remain even in 2050 because some types of oil such as heavy oil must continuously be used for transportation. According to the assumptions, the combination of gasoline cars and DAC may be considered cost-efficient comparing to electric vehicles. Accordingly, in some scenarios, a certain amount of gasoline cars is still estimated for 2050. Moreover, the use of CCS with gas power plants is estimated to be cost-efficient compared to renewable energies. These results depend on assumptions such as costs for CCS/DAC and fuel prices.

*Figure 6: Final energy demand in 2050 [TWh]*

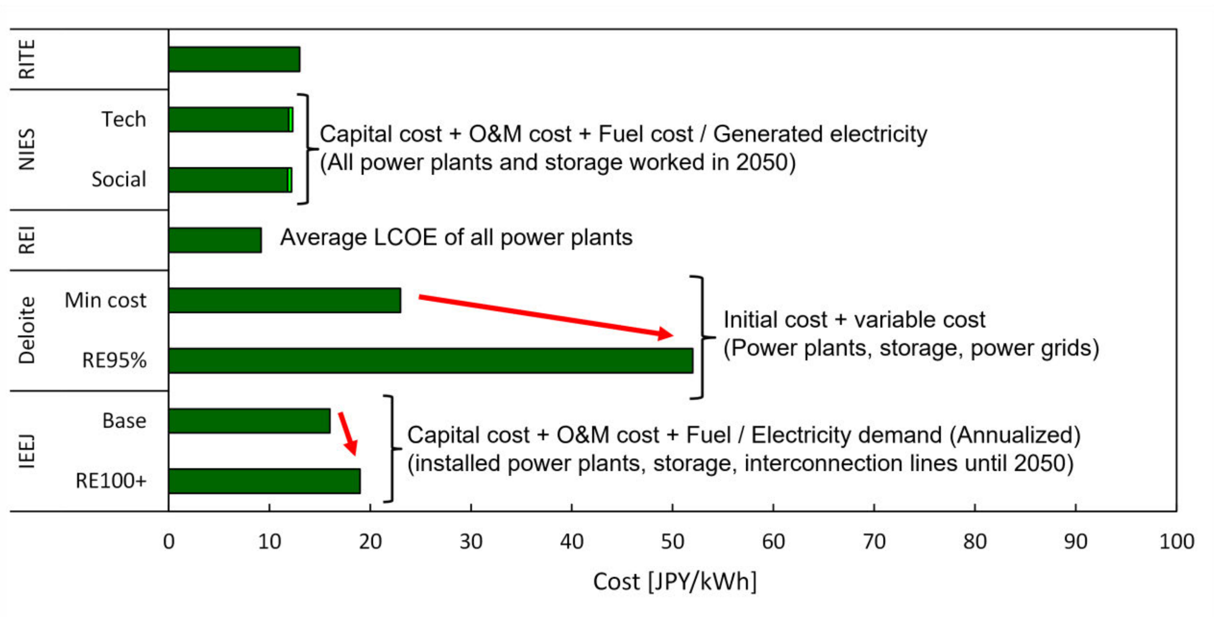



GJETC: Long-term scenario analysis

### 4.2.4 Average costs in the electric power sector

All scenarios show the average costs in the electric power sector. It should be noted that the definitions of average costs are different among the models. For example, while REI shows the lowest average costs, the value is defined as an average LCOE of all power plants. NIES shows costs dividing the total of capital costs, O&M costs, fuel costs of all power plants and storage by generated electricity. Deloitte shows average costs depending on initial costs and variable costs of power plants, storage, and power grids. IEEJ defines the average costs as the value obtained by dividing the total costs including capital cost, O&M cost, fuels cost, by the annualized electricity demand of installed power plants, storage, interconnection lines. Despite these differences of definitions, the average costs tend to increase as the percentage of renewable energy increases.

*Figure 7: Averaged costs in power sector [JPY/kWh]*

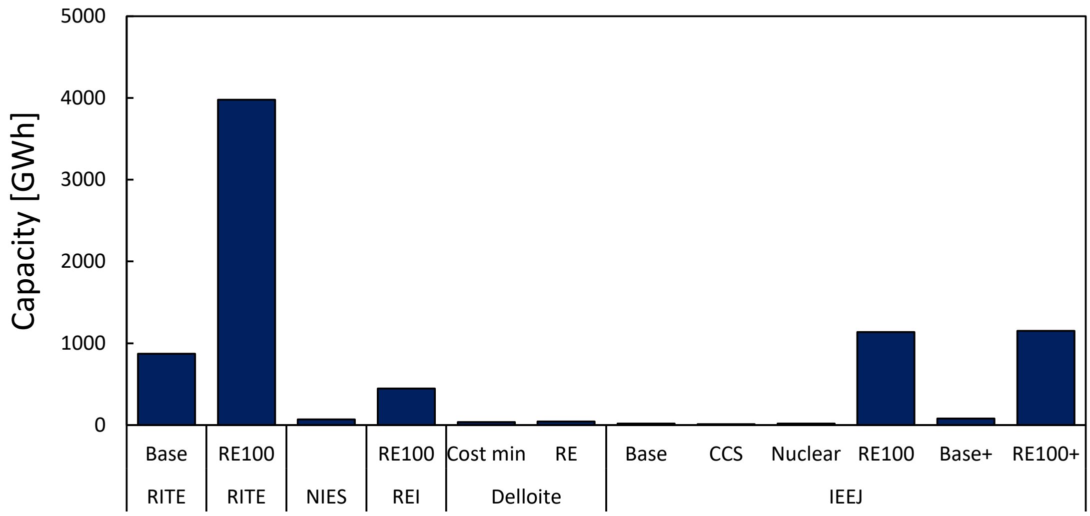



### 4.2.5 Storage capacity

While the percentage of generated electricity from renewable energy is expected to be 40-100%, some scenarios show extremely high percentages of renewable energy. These results depend on the availability of hydrogen or the potential of electric vehicles. In these scenarios, backup power plants such as thermal power plants with CCS and nuclear power plants tend to be excluded. Instead, these scenarios show a massive amount of storage capacities (> 1,000 GWh).

If 10 kWh storage systems were installed in all currently existing residential homes (29 million), the total storage capacity would be only 290 GWh (10 kWh x 29 million). Compared to this, the necessary storage capacity to assure electricity supply security is significantly larger.

*Figure 8: Storage capacity [GWh] in 2050*




## 4.2.6 Main implications

As the model approach and assumptions by each organization are different, the main results of each organization also differ.

RITE implies that various technologies and innovations such as hydrogen generation, ammonia generation and CCUS are necessary to reach carbon neutrality. Moreover, policy support for several fields is necessary. Similarly, IEEJ implies various options being utilized for carbon neutrality such as nuclear energy generation, hydrogen generation, ammonia generation, and CCUS. Moreover, a balanced energy mix is required.

NIES assumes that the decarbonization may cause losses of national wealth. Furthermore, social transformation may ensure/enable decarbonization. REI estimates that

decarbonization is possible not only in the electricity supply but also in the heat and transport sectors by utilizing renewable energies.
Deloitte assumes that a percentage of renewable energy of 71% in the electricity generation may lead to a doubling of electricity prices compared to the current price levels for realizing carbon neutrality.
Thus, while some organizations stress the difficulty of achieving carbon neutrality in the power sector and the need for various technologies, others assume that decarbonization may give positive impacts.

# 5. Analysis of German scenarios

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## 5.1 Methods used and key assumptions

### 5.1.1 Scenario approaches, models and methods used

Most German scenarios are based on back-casting modelling approaches (policy scenarios): The necessity of reaching carbon neutrality in 2045/2050 is *presupposed* according to the Paris Agreement (2015) and a national *just* contribution to the global "well below 2 degrees"-target calculated by the so-called *budget approach*[3]. The scenarios investigate technically and economically possible strategies to reach the presupposed carbon neutrality target in 2045. Detailed information on the models used in the selected studies was only partially available.

The climate neutrality scenario 2045 of the **Agora study** (in German: Klimaneutrales Deutschland 2045, KN45) is a diversified technology scenario. In comparison to a former

[3] The budget approach starts with the calculation of the remaining global $CO_2$-budget compatible with the targets of the Paris Agreement and - by a per capita basis distribution – calculates the corresponding available residual budget e.g. for Germany under certain probability assumptions www.wbgu.de/fileadmin/user_upload/wbgu/publikationen/factsheets/fs3_2009/wbgu_factsheet_3.pdf).

scenario analysis with the target year 2050, KN45 scenario relies primarily on the rapidly accelerated and more comprehensive use of the already projected approaches of climate-friendly technologies and strong climate policies for climate neutrality. The basic approach: energy efficiency, renewable energies and electrification, green hydrogen and ca. 5% of negative emissions. The modelling of KN45 follows the same approach as the Agora scenario KN50 published in 2020. They are based on eight different sector models: the EU-wide electricity market model, private household model, commercial and public sector model, transport model TEMPS, agriculture model LiSE, LULUCF model FABio, waste model WaSMOD and the industry model WISEE-EDM. The approaches differ in the various sectors and range from merit-order modelling, including power imports and exports, in the electricity market model to a bottom-up approach in the end-use sector models, modelled by end-use and fuels. The power demand resulting from the end-use sector models is converted to load curves, including flexibility potentials, as an input to the hourly scheduling of power plants according to their merit order.
Hence, this study models GHG emissions from all sectors, including the often neglected sectors agriculture, waste and land use (Agora 2021: 23). The GHG emissions' assessment is based on the inventory report of the UNFCCC estimating a GHG potential for 100 years for all greenhouse gases (4th Assessment report of the IPCC, IPCC AR4).

According to the motto "Energy mix of the future: electrons and molecules", the **German Energy Agency (dena) study** generally relies on comparable four pillars as the Agora study, but with an emphasis on innovations and a higher share of hydrogen and other Power-to-X (PtX)[4] fuels. The authors emphasize additionally the importance of an integrated overall strategy with a holistic, political approach, $CO_2$ pricing and social transformation. As all other studies, it is based on sectoral balance sheet limits that are in line with the German Climate Protection Law (KSG21) (cf. chapter 3). Final energy consumption and greenhouse gas emissions are calculated according to the source principle, attributing $CO_2$ emissions

[4] Various technologies for storing or otherwise using electricity surpluses in times of oversupply of variable renewable energies

to specific countries and sectors in which they were generated. Equally to the Agora and BDI scenario, the described GHG reduction targets of the Climate Protection Law (KSG21) are the central parameters for the modelling of the KN100 scenario. In 2030, the sectoral reduction targets for the sectors of transport, industry, buildings and energy are each set as quantity restrictions in the EWI[5] energy system model DIMENSION, which optimizes the future development of power plants, renewable energies and flexibility options (including electrolyzers) for the provision of energy in 28 European countries. In doing so, the model maps the cost-minimizing use and capacity expansions as well as the dismantling of various technologies. According to the EWI, the emissions of the agriculture sector are not explicitly modelled in this study, but are rather taken from the results in the Agora study, which are discussed in this comparative study as well.

The study of the **Federation of German Industries (BDI)** considers Germany's goal to reach GHG neutrality by 2045 the "greatest transformation in its post-war history" (Climate Paths 2.0 2021: 2, English summary) requiring fundamental changes in the energy system (including the international energy supply), the building and vehicle stock, infrastructure and large parts of energy intensive industries. More specifically, the authors mention the acceleration and intensification of energy-efficiency measures as well as the green electrification which necessitates a significant expansion of renewable energy capacities (by a factor of 4 in 2045 compared to 2019).
The BDI study does not explicitly explain the applied modelling approach. The authors declare, however, that their "comprehensive, open to all types of technologies analysis" (Climate Path 2.0 2021: 1,2, English summary) is based on bottom-up approaches and realized in dialogue with experts from specific industries and associations of the German industry. The focus of the analysis lays on the calculation of current investment and operation costs concerning a broad range of mitigation technologies and measures.

[5] Institute of Energy Economics at the University of Cologne.

The **GreenSupreme Scenario** of the German Environment Agency (UBA) is the only German scenario that focuses on both reducing THG emissions and the use of resources , while combining technical options with sufficiency policies and behavioral changes. As it was written in 2020, before the climate protection law was revised, it refers to climate neutrality by 2050. Still, it is one of the most ambitious scenarios published in Germany. Its strategies: (1) transformation of the energy system with a rapid shift to renewables across all sectors and smart sector coupling, (2) ambitious energy demand reductions through both energy efficiency and sufficiency (behaviour) (3) conversion of emission-intensive industrial processes to low or zero-emission processes, (4) the reduction of production volumes through circular strategies, but also lifestyle changes and (5) the substitution of fossil raw materials by secondary, biotic and lighter raw materials.
The scenario is based on different Input-Output models for each sector by considering specific sector assumptions. For instance, to model the effect of resource efficiency the URMOD model is used[1].

### 5.1.2 Framework conditions and key assumptions

The German scenarios mostly focus on potentials, demand and replacement of existing technologies in the energy, building, transport and industry sectors that constitute relevant factors for finding economic solutions on the way to climate neutrality. The agricultural and waste or land use sector, land use or GHG emissions related to biomass are only considered by the Agora and UBA studies.

In line with the revised Climate Protection Law 2021, the three recent studies refer to the new more ambitious reduction targets (Climate Protection Law 2021, KSG). Although the UBA study was published earlier and therefore is targeting on reaching climate-neutrality by 2050, its emphasis on a fast and strong reduction of $CO_2$ emissions is apparent in its stronger ambition until 2030 (-70%). Three of four scenarios assume that the current demographic and economic development will be maintained (cf. table 6). Only the UBA study follows a new path regarding the assumed economic growth. While BDI, Agora and dena expect a constant or slightly declining GDP ranging from 0,9% to

*Table 6: Framework conditions*

*): Prices in the BDI study are inflation-adjusted with the reference year 2019. The other studies give

| Indicator | year | Agora 2045 | Dena 2045 | BDI 2045 | UBA GreenSupreme 2050 |
|---|---|---|---|---|---|
| **GHG reduction targets compared to 1990** (in %) | 2030 | -65 | -65 | -65 | -70 |
| | 2045 | -100 | -100 | -100 | 2050: -100 |
| **Population** (number in million) | 2020 | 83 | 83 | 83 | 83 |
| | 2045 | 80 | 81 | n.a. | 74 |
| **Households** (number in million) | 2030<br>2045 | 43<br>43 | n.a.<br>n.a. | n.a.<br>n.a. | n.a.<br>n.a. |
| **GDP growth rate** (in %) per year | 2018<br>2030<br>2045 | 1.3<br>ca. 1.0<br>ca. 1.0 | 1.3<br>0.9<br>0.9 | 1.3<br>1.3<br>n.a. | 1.3<br>0<br>0 |
| **Primary energy demand** (in TWh) | 2018 | 3,646 | 3,646 | 3,646 | 3,646 |
| **Energy prices*)** (EUR/MWh)<br>Oil | 2030<br>2045 | 34<br>31 | 45.8<br>60.6 | 29.88<br>n.a. | n.a. |
| Gas | 2030<br>2045 | 20<br>22 | 17.9<br>23.7 | 13.3<br>n.a. | n.a. |
| Coal | 2030<br>2045 | 8<br>8 | 10.3<br>10.2 | 6.5<br>n.a. | n.a. |
| **EU ETS $CO_2$ Price:** $EUR_{2019}/t$ | 2030<br>2045 | 52<br>80 | n.a. | 72<br>n.a. | n.a. |

no further information about the inflation-adjustment.

1,3% (2030-2050), the UBA study indicates a departure from the growth paradigm after 2030 by a growth rate of 0.[6]

The importance of market-driven instruments for reaching climate neutrality is emphasized in all studies. However, only the BDI study provides explicit values of the $CO_2$-prices, both in the EU ETS context and in relation to the $CO_2$-price regulated by the Fuel Emissions Trading Act (German: Brennstoffemissionshandelsgesetz, BEHG) on the national level.[7] According to the BDI study, the latter ranges from 65 €/t to no less than 150€/t depending on the policies that go along with it.

The German scenarios also include sector- and technology-specific assumptions on energy efficiency and end-use technologies (see table 7).

*Building sector*

In the building sector, all studies assume a clearly increased renovation rate that improves the energy efficiency of the building stock and rises on average up to 2% per year in 2045 (compared to about 1% in the past). Again, the UBA GreenSupreme scenario assumes much higher rates, both in 2030 and 2045, achieving even 3,6%. As an important condition for the decarbonization of the heating sector, all studies consider the expanded use of heat pumps and expect their numbers to rise from 1,3 million to a maximum of 6 billion in 2030 and ca. 15 million units in 2045.

*Transport sector*

A basic assumption of all scenarios in the transport sector is its electrification. Starting from 516,518 all-electric vehicles in 2021, the analyzed scenarios expect between 9 and 14 million battery-electric vehicles in 2030. Regarding 2045, however, the studies reveal different assumptions: while Agora, dena and BDI consider between 32 and 39 million all-

[6] The average GDP growth rate from 1990-2020 was 1.3%, with a decreasing trend (1990-2000: 1.9%; 2000-2010:0.9%; 2010-2020: 1.1%).

[7] While the Agora study considers only the EU ETS prices under the current EU ETS system. The $CO_2$-pricing according to the BEHG goes even beyond what is to be expected by the new (expanded) EU ETS (see Climate Path 2.0: 43).

electric vehicles in 2045, the UBA GreenSupreme-scenario stands out with its approach of sufficiency: in addition to the 100% electrification strategy of the motorized individual transport modes, the authors are clearly moving away from the passenger car, but emphasize a modal shift towards environmental-friendly means of transport such as

*Table 7: Key assumptions: sectoral assumptions*

| | | Agora 2045 | Dena 2045 | BDI 2045 | UBA GreenSupreme 2050 |
|---|---|---|---|---|---|
| **Renovation rate of buildings stock** (in % per year) | 2030 | 1.6 | 1.8 | 1.9 | 2.5 |
| | 2045 | 1.7 | 1.9 | 2.1 | 3.6 |
| **Heat pumps** Number of units (% of heat in buildings) | 2030 | 6 mn (24%) | 4 mn | 6 mn | n.a. |
| | 2045 | 14 mn (60%) | 9 mn (42%) | 15 mn | 2050: 16 mn (75%) |
| **Battery-electric Vehicles** Number of units (% of inventory structure) | 2030 | 9 mn (19%) | 9 mn (n.a.) | 14 mn (31%) | 12 mn |
| | 2045 | 34 mn (91%) | 32 mn (n.a.) | 39 mn (86%) | 2050: 18 mn |
| **Annual full-load hours 2030** (on = onshore; off = offshore) | PV | 957 | 946 | n.a. | n.a. |
| | Wind | On: 1,888<br>Off: 3,600 | On: 2,348<br>Off: 4,043 | On: 2,122<br>Off: 3,786 | n.a.<br>n.a. |
| **Investment costs 2030** (in €/kW/2019) | PV | rooftop: 750<br>utility scale: 400 | rooftop: 733<br>utility scale: 640 | rooftop: 850<br>utility scale: 500 | n.a. |
| | Wind | On: 1,100<br>Off: 2,000 | On: 1,038<br>Off: 1,920 | On: 950<br>Off: 1,490 | n.a. |
| **Crude steel production 2045** (in million t / a) | | 39.6 | 42.4 | n.a. | 34.5 |
| **Cement production 2045** (in million t / a) | | 27.5 | 33.0 | n.a. | 17 |
| **Paper production 2045** (in million t / a) | | 25.1 | 24.1 | n.a. | 14 |

public transportation, bicycle, pedestrian traffic. The number of all-electric vehicles rises to only 18 million in 2050, because the total number of individual vehicles is assumed to reduce by at least half.

*Energy sector*

Regarding renewable energies, the selected scenarios rather differ little in their assumptions on full-load hours or investment costs. The dena and BDI study appear to be slightly more optimistic regarding wind energy. Regarding the investment costs for wind energy and photovoltaics, the scenarios assume different learning curve effects. But they all commonly expect decreasing costs in the future.

*Industry sector*

In the industry sector, production volumes of crude steel, cement and paper are similar between Agora and dena. A radical difference in the basic approach becomes apparent when considering the numbers presented by the UBA GreenSupreme scenario: the stated quantities in the paper and the cement production are significantly lower and underscore the immanent principles of sufficiency. As the BDI study only provides numbers for 2030 it has not been considered further in comparing these indicators.

## 5.2 Key results

The German scenarios describe what pathways to climate neutrality for the various sectors of the energy system could look like. In principle, there can be identified four common approaches and basic strategies. However, each scenario has its own characteristics and differences when compared to the others.

### 5.2.1 Reducing the energy demand

An ambitious reduction of the energy demand through efficiency measures in all sectors is considered to be the first important pillar to reduce the GHG emissions. It is also a basic requirement to secure the energy supply through the extensive use of renewable energy in all German scenarios. Efficiency potentials are seen especially in the building and the transport sector where e.g. renovation, use of heat pumps, all-electric vehicles have much higher degrees of efficiency. As a result, the final energy demand decreases significantly from 2,500 TWh (2018) to 1,300-1,600 TWh in 2045 (approximately -36%). The UBA scenario combines the energy efficiency approach with resource efficiency and even reaches a final energy demand reduction of -57% until 2050. Primary energy is calculated to see a 50% reduction between 2019 and 2045. Here, the BDI scenario achieves only -44% reduction (cf. table 8).

It should be noted that the implementation of energy efficiency and energy conservation policies up to now, does not satisfactorily correspond with the partly ambitious energy efficiency approach of the scenarios. Evaluations point out existing gaps between possible efficiency potentials and scenario results, also when compared to the targets of the government[8]: "Between 2008 and 2019, final energy productivity improved by an average of 1.4 percent annually, which is well below the target of 2.1 percent annually" (*8th Monitoring Report 2022*: p.74, own translation). This indicates that not only for renewable energy, but also for energy efficiency the ambition level of policy, industry and the civil society must be raised to catch up with the path to climate neutrality as demonstrated in all scenarios. Considering the assumptions for GDP growth rates shown above, the scenarios would result in final energy productivity improvement rates of around 3 percent annually on average.

*Table 8: Energy demand reduction in German scenarios*

| | | Agora 2045 | Dena 2045 | BDI 2045 | UBA GreenSupreme 2050 |
|---|---|---|---|---|---|
| **Final energy demand reduction** (compared to 2018) | **2045** | -36,1% | -36,3% | -36% | 2050: -56,8% |

[8] https://www.bmwi.de/Redaktion/EN/Publikationen/Energie/the-energy-of-the-future-8th-monitoring-report.pdf?__blob=publicationFile&v=6.

| | | | | | |
|---|---|---|---|---|---|
| **Savings in primary energy** (compared to 2018) | **2045** | -50,8% | -50,7% | -44,2% | n.a. |

*Figure 9: Total final energy demand in German scenarios (in TWh)*

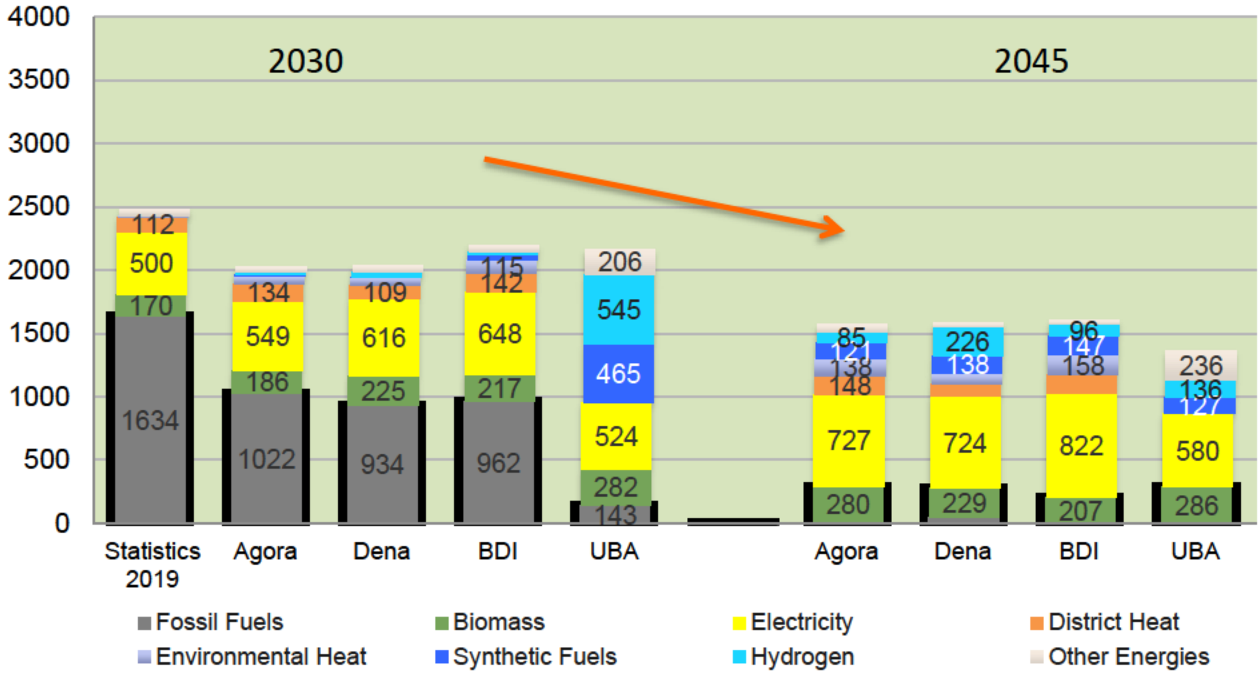
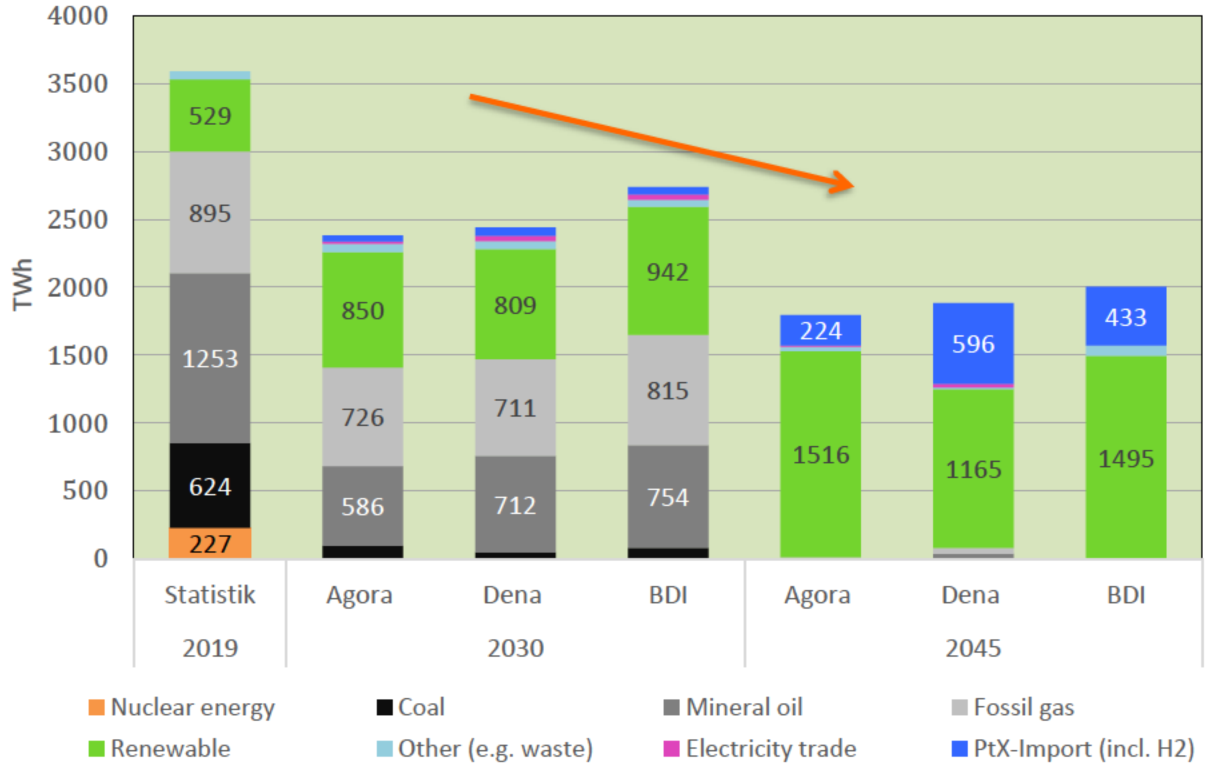



*Figure 10: Primary energy demand (in TWh)*




### 5.2.2 Transformation of the energy mix: Renewable energy and electrification

While the energy demand is decreasing, figures 9 and 10 also show that at the same time there is a strong change in the energy mix. The scenario studies by Agora, BDI and UBA suggest a phase-out of coal until 2030, 8 years earlier than what the former coalition decided in 2021.[9] Nuclear energy will be phased out by 2022. The share of other fossil fuels decreases to zero by 2045. Both renewable energy as an available, cost-efficient energy source and green electricity are becoming increasingly important. Moreover, hydrogen and PtX fuels become relevant after 2030.

*Renewable energies*

In all 4 scenarios, shifting the energy production to renewable energy sources is considered to be the second major strategy towards climate neutrality. There is an

[9] The new coalition actually seeks to phase-out coal until 2030.

additional power demand for the domestic generation of green hydrogen and hydrogen-based PtX fuels as well as non-energetic uses in the industry.

The share of renewable energy sources in electricity generation increases from 44% (2020) to 60 to 86% in 2030 and almost 100% in 2045. The BDI study sets only 60% in 2030, because it assumes an even faster electrification, leading to higher total power demand, while the UBA study with 86% is even higher, indicating a significantly faster electrification.[10] It should be noted that the new government's target of reaching a share of 80% renewable power by 2030 exceeds the assumed share of renewables in three out of the four studies analyzed here. The same is true for the electrification goals, e.g. the number of electric vehicles.

In regards to primary energy, the share of renewable energy increases from currently 16,4% (2021) to 31%-38% in 2030 and 93%-97% in 2045.[11] Renewable energies such as geothermal and solar thermal also play an important role in the heating and cooling sector. Germany will have to accelerate the expansion of renewable energy production significantly. Figure 11 shows the *annual gross increases* until 2030 which will double or even triple compared to the last years. The biggest annual increases are seen for PV (8-10 GW), wind onshore follows with 5-11 GW. This ambitious capacity increase underscores that the restrictive upper limits of installation, zoning rules and spatial planning of the past must be revised in favour of a very challenging expansion strategy.

The resulting *electricity production capacities* of renewable energies are expected to reach on average 140 GW for PV, 90 GW for wind onshore and 25 GW for wind offshore until 2030 (cf. table 9). In the following phase up to 2045, the scenarios show different dynamics: While Agora sees a further massive expansion of PV with 355 GW in 2045, the

[10] While the studies conducted by Agora and dena still consider a small amount of natural gas (Agora: 2%, dena: 1%) in the electricity production of 2045, in the BDI-scenario the phase-out will be already completed then. Also, contrary to Agora and dena, the electricity production refrains from net electricity imports in the BDI study. The share of renewable energy in the net power generation including net power imports, in all 4 scenarios rises to 67-84% in 2030, and reaches 100% by 2045.

[11] While the studies conducted by Agora and dena still consider a small amount of natural gas (Agora: 2%, dena: 1%) in the electricity production of 2045, in the BDI-scenario the phase-out will be already completed then. Also, contrary to Agora and dena, the electricity production refrains from net electricity imports in the BDI study.

BDI-study and dena are more reserved with only 230-260 GW, UBA even expects only 130 GW of installed capacity. BDI sees the highest wind onshore potential with 180 GW installed capacities in 2045.

Most of the scenarios do not focus on price developments and integration costs in particular. The GreenSupreme Scenario for instance describes the direction of price developments (as constant or as shifting slightly upward) but without any quantification. However, based on the low-cost flexibility potentials that they identify, the studies do not consider *integration costs* as a major challenge for reaching climate neutrality. According to BDI, such a vast expansion of renewable energy will cause system costs amounting to 73-104 billion Euro (Climate Path 2.0 2021), related to the expansion of the electricity grid (13 billions EUR), the accelerated expansion of renewable energies (13

*Table 9: Expansion of renewable energy*

| | | Agora 2045 | Dena 2045 | BDI 2045 | UBA GreenSupreme 2050 |
|---|---|---|---|---|---|
| **Primary energy:** Share of renewables | 2030 | 37.6% | 33.1% | 31.2% | n.a. |
| | 2045 | 97.0% | 93.3% | n.a. | n.a. |
| **Electricity generation:** Share of renewables, including hydrogen and waste from renewables | 2030 | 70,8% | 75% | 59,9% | 85,5% |
| | 2045 | 100% | 100% | 100% | 100% |
| **Installed electricity production capacities** (GW) | 2030 | PV: 150<br>Wind on: 81<br>Wind off: 25 | PV: 131<br>Wind on: 92<br>Wind off: 23 | PV: 140<br>Wind on: 98<br>Wind off: 28 | PV: ca. 105<br>Wind on: 104<br>Wind off: ca. 16 |
| | 2045 | PV: 385<br>Wind on: 145<br>Wind off: 70 | PV: 259<br>Wind on: 124<br>Wind off: 50 | PV: 230<br>Wind on: 180<br>Wind off: 70 | 2050: PV: 130<br>Wind on: 127<br>Wind off: 30 |
| **Difference in Electricity System** | 2030 | n.a. | n.a. | -0.1 | n.a. |

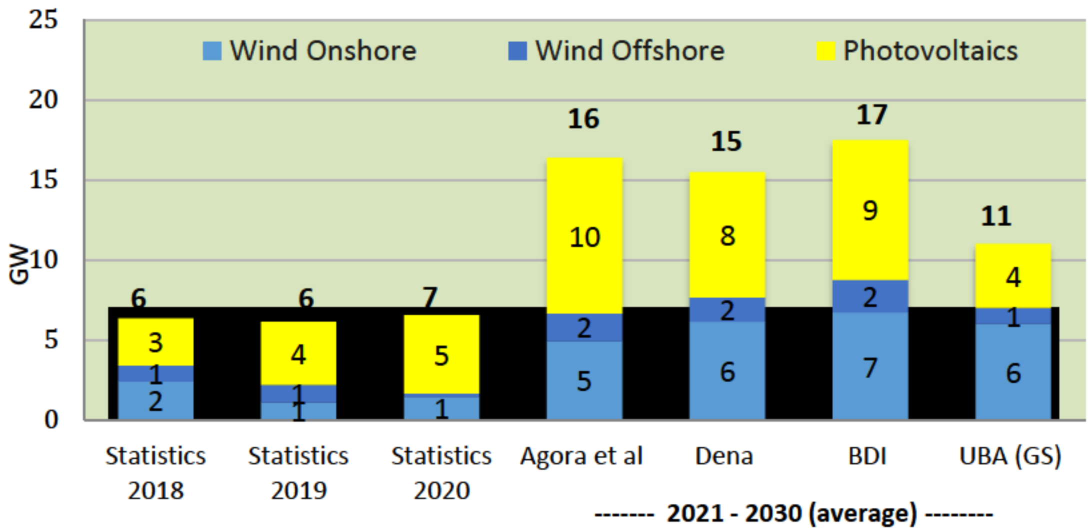
| | | | | | |
|---|---|---|---|---|---|
| **Costs** (Eurocent/kWh, compared to reference) | 2045 | n.a. | n.a. | +0.6 | n.a. |

billions EUR) and the construction of "$H_2$-ready" gas-run power plants (5 billions EUR). These costs are estimated to be largely passed on to the end-users (ibid). However, the electricity prices are expected to only rise slightly (+0.6 Eurocent/kWh in 2045), due to an overall increase of electricity demand related to new applications entering the market (see figure 13). Moreover, the authors of the BDI-study assume that the renewable energy levy will be abolished, leading to a considerable decrease of customer prices per MWh (Climate Path 2.0, 2021). This assumption corresponds with the decision of the Federal Cabinet of March 2022. [12]

Expanding renewable energies in densely populated Germany will be a challenge especially for onshore wind energy. Potential studies of the UBA (2013/2019) on the possibility of increasing wind energy onshore (UBA 2019) show that, theoretically, there is sufficient space (UBA 2013; UBA 2019a). But zoning rules, environmental and nature conservation aspects, social restrictions and lengthy approval procedures pose an obstacle. Further land use conflicts due to grid, storage, electrolysers and CCS/DAC are to be expected. Considering environmental and nature conservation aspects, UBA identifies an area of (roughly) 7,800 km$^2$ to be available for onshore wind energy use, on which an installed capacity of around 200 GW would be possible.

[12] https://www.bundesregierung.de/breg-en/news/renewable-energy-sources-act-levy-abolished-2011854.

*Figure 11: Annual gross increases of wind and PV capacities (in GW)*




*Electrification*

Technology shift and the electrification in all sectors, especially transport, building and industry sector enables displacement of conventional fossil energy sources. It thus represents an important and particularly efficient strategy to decarbonization. The share of electricity contributing to the total final energy demand increases in almost all scenarios from 20% (2019) to ca. 41-51% in 2045 (cf. figure 9). Particularly the expansion of electric vehicles, heat pumps and electrolysers for the ramp-up of green $H_2$ production, but also the stronger use of other power-based processes in the industry contribute to the increase in power demand (see figure 13). Differences in the assumed growth in these numbers among the 4 scenarios are also reflected in the results, showing different quantities of net power generation needed. The power generation will nearly double from ca. 540 TWh to ca. 1,000 TWh between 2019 and 2045 (see figure 12).

*Figure 12: Net power generation by fuel plus power imports (w/o pumped hydro and batteries) (in TWh)*

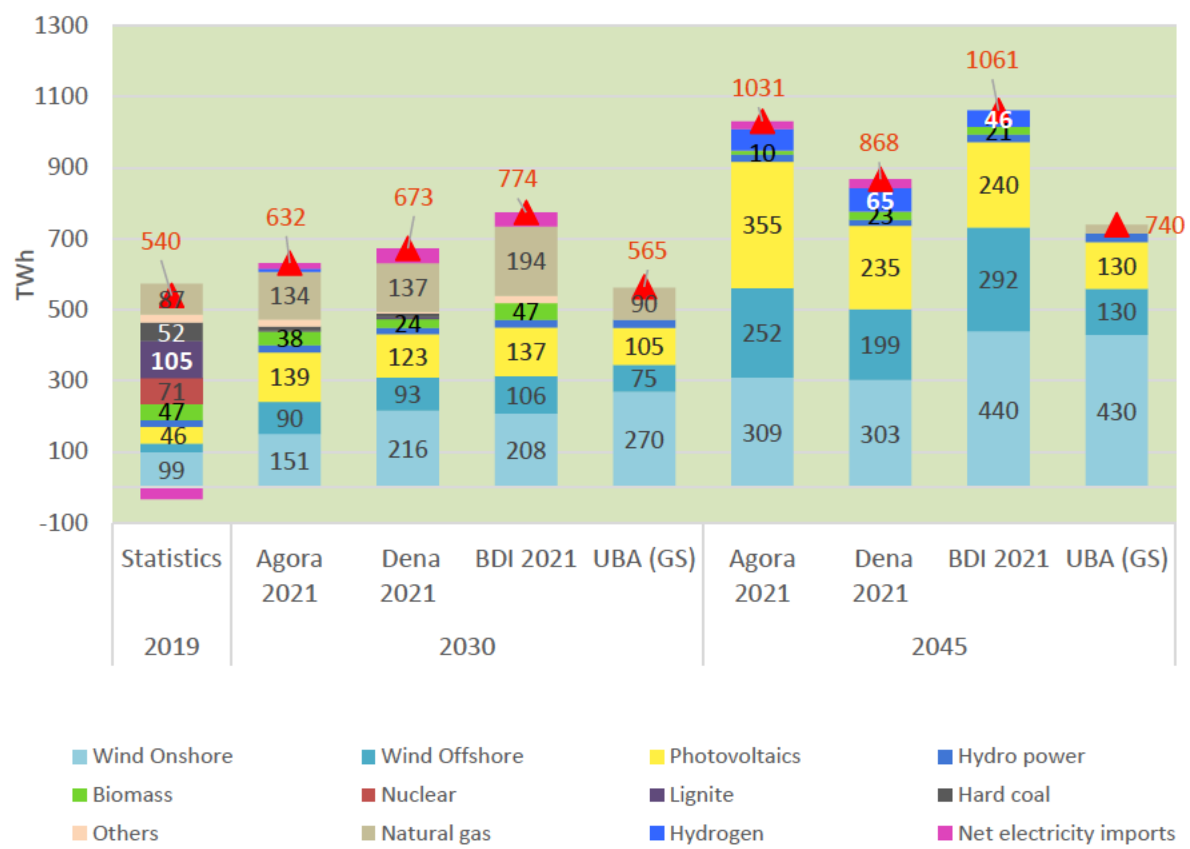
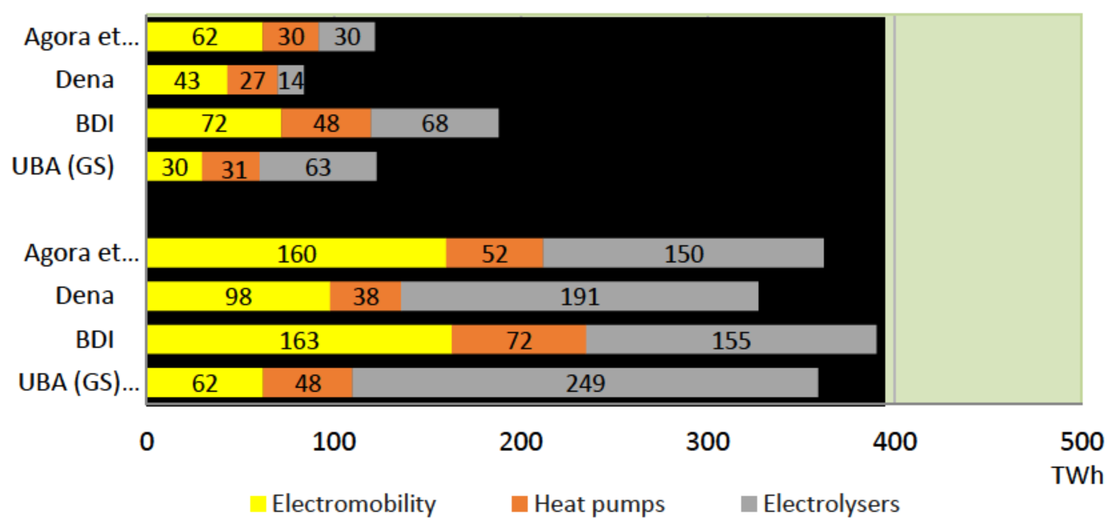



*Figure 13: Power demand of "new" uses of electricity (in TWh)*



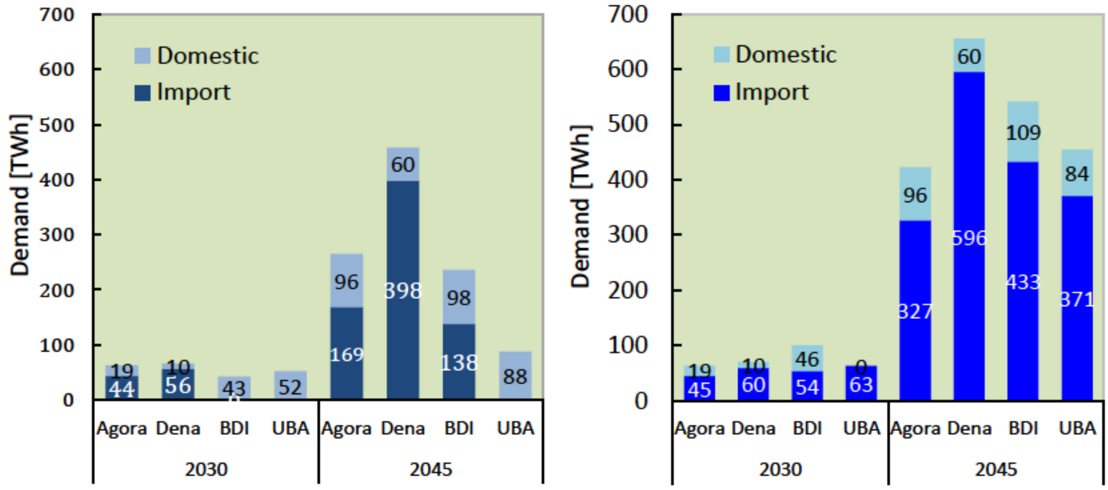
### 5.2.3 Hydrogen and PtX as energy source and raw material

However, renewable energy and electrification alone will not be enough to decarbonize the economy. In some fields gaseous and liquid energy sources will still be needed so that the decarbonization of the industry, the energy and the transport sector in Germany also strongly depend on an increasing use of hydrogen and PtX. Hydrogen will be used for power generation, DIR, as raw material in the basic industry, for process steam generation and for heavy freight, fuel cells of trucks and semi-trailers. PtX will be especially used in international shipping and air traffic, thus reaching a significant importance in 2045.

Figure 14 shows the hydrogen and PtX synfuels demand in 2030 and 2045 and it illustrates a considerable big range of expected production amounts. The dena study estimates the highest production quantities, both for hydrogen (458 TWh) and synfuels (656 TWh) in 2045, while the UBA GreenSupreme scenario considers much fewer capacities (Hydrogen: 88 TWh, PtX: 455 TWh) in 2045.

While all studies emphasize that the domestic hydrogen and synfuel production would be preferable, it is mostly assumed that Germany will continue to be an energy import country. To meet the GHG emission reduction goals and ensure the financial feasibility, significant imports will be needed: for hydrogen between 60-90% (130-400 TWh), for PtX ca. 77-90% (320-600 TWh). Only the UBA GreenSupreme scenario considers hydrogen to be fully produced domestically by 2045. This needs to be related to the overall lower energy demand that the UBA GreenSupreme scenario assumes, according to which the domestic green power potentials would be sufficient to cover the green hydrogen production. Samadi/Lechtenböhmer (2022) underline, however, that the energy imports in 2045 will be 70 percent less than today´s imports of fossil energy sources.

*Figure 14: Hydrogen and PtX-Synfuels demand*

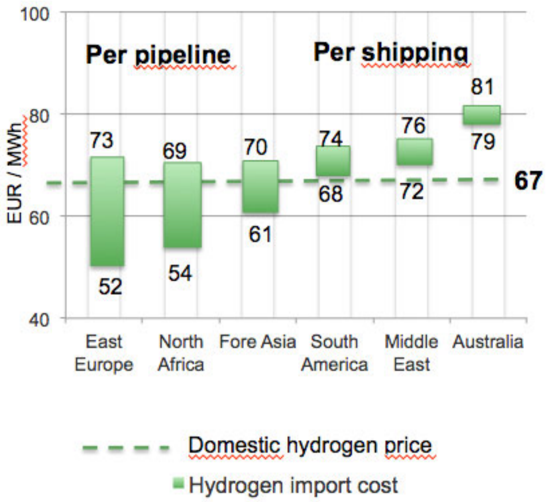



Since hydrogen for the time being will be mostly imported, the price will depend on the region of origin and the means of transport. Figure 15 extracted from the dena study, illustrates the respective price differences arising for imported hydrogen: Countries outside Europe often have better conditions for renewable electricity production. However, the more favorable production conditions are countered by longer distances for hydrogen transport. Especially for distant countries, from where hydrogen is transported to Germany by ship, transportation costs account for a large share of the total hydrogen import costs. The import via pipelines from Eastern Europe, North Africa, Middle East appears cheaper than by ship from South America, Middle East and Australia. Accordingly, the price range fluctuates. Finally, geopolitical considerations must be as well taken into account, as the current situation in Eastern Europe painfully shows.

It is commonly agreed in all studies that *green* hydrogen production has to be pursued. Natural gas will drop to almost zero in 2045. Accordingly, in 2045/2050, almost all gas for power plants has to be green hydrogen to reach carbon neutrality. This implies that power plants in the period 2030 to 2045 fed by natural gas must be constructed “hydrogen-ready” to convert them gradually to hydrogen.

In addition to the optimized use of biogenetic energy sources, the studies project a need for further engagement in the national and international market development of power fuels.

*Figure 15: Hydrogen import costs by region in 2045 (dena 2021)*

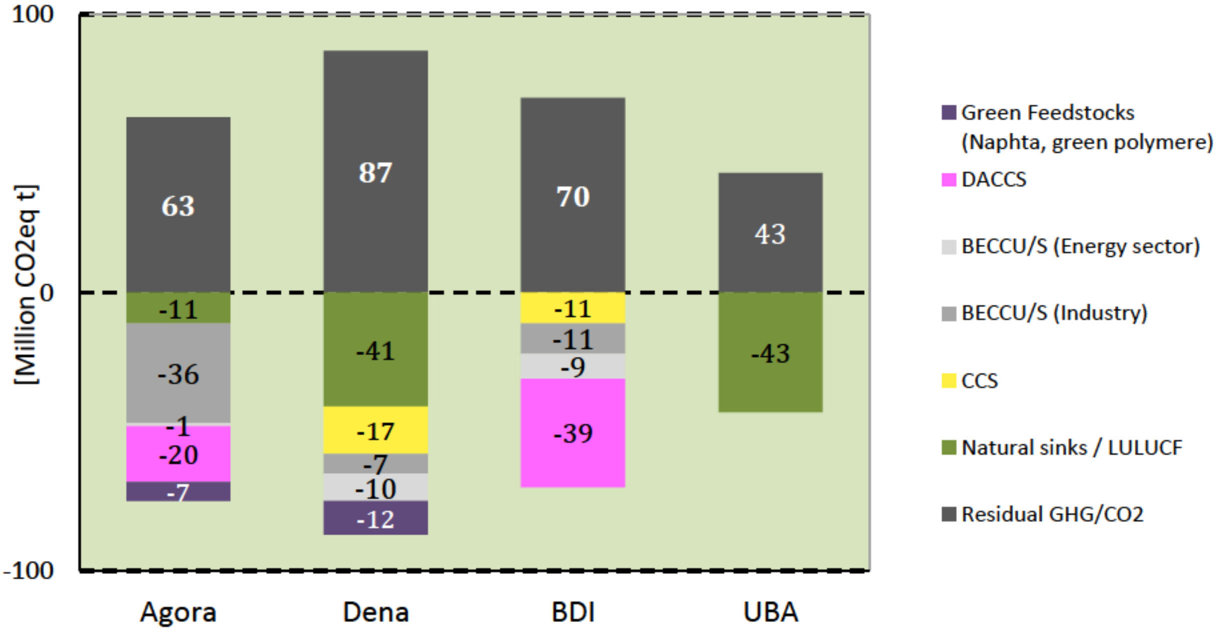



## 5.2.4 Removing residual greenhouse gas emissions

It is expected that despite all measures and efforts, some greenhouse gas emissions particularly in the agriculture, industry and waste sectors, will remain inevitable. For 2045, the analyzed scenarios expect residual emissions of about 43 to 87 billion $tCO_2eq$ (cf. Figure 16). These amounts range from about 5 to 10% of the emissions in 1990 and compensation appears feasible. But the relevance of technical and/or natural sinks is considered quite differently across scenarios. Especially the authors of the Agora and BDI study claim that the use of direct and indirect carbon capture technologies needs to be practiced earlier and with more emphasis. Most of the scenarios emphasize BECCS as a main strategy. Dena and BDI also assume some CCS for natural gas, and BDI considers DACCS as the most important option.

The GreenSupreme Scenario does not focus on technical measures for carbon dioxide storage (CCS) because CCU is required for the provision of electricity-based hydrocarbons (in PtG/PtL technologies). But since national priority is given to the production of hydrogen for industry, the nationally produced PtG quantities are limited and thus also the need for $CO_2$ sources. Instead, the GreenSupreme focuses solely on natural sinks. Also, the dena study states natural sinks as a major option.

*Figure 16: Technical and natural negative emissions 2045 (in million $tCO_{2eq}$)*



# 6. Japanese German Comparison

Authors: The Institute of Energy Economics, Japan and Wuppertal Institute for Climate, Environment and Energy

The selected scenarios in both countries follow a back-casting approach, seek to reach economic solutions with a focus on cost efficiency and are assuming similar framework conditions. Identified common strategies to reach climate neutrality are the reduction of energy demand, the shift in energy mix towards climate neutral energy carriers, and the electrification and compensation of residual GHG emissions through technical sinks. However, details, characteristics and targeted shares differ, as shown below.

## 6.1 Improving energy efficiency

**Japan:** The primary energy demand on average decreases about 33%, only REI is more ambitious with a reduction of 50% until 2050 (from ca. 5,100 TWh in 2020 to a range of 4,700 (NIES) to 2,000 TWh (REI)). The final energy demand decreases by 30% (from 3,361 TWh to approximately 2,500 TWh). The analyses of the demand side are not sufficiently shown by current studies. In the future, it is recommended to assess the impact/potential on the demand side in more detail.

**Germany**: Improving energy efficiency is a key point to reduce $CO_2$. In the analyzed scenarios, the primary energy demand between 2019 and 2045 decreases on average by 50% (from 3,557 TWh to a range of 1,883 to 1,794 TWh), with the BDI scenario achieving a reduction of 44% (2,003 TWh). The final energy demand in the analyzed scenarios decreases between 2019 and 2045 by 36% (from 2,484 TWh to a range of 1,604 to 1,572 TWh), whereas for the UBA scenario that has a special focus on energy efficiency and sufficiency, it even reaches a decrease of 57% (1,365 TWh). Potentials must be fully exploited according to the UBA scenario, even if this may exceed the current targets and strategies of the government.

## 6.2 Energy mix

**Japan:** Concerning the primary energy mix, the Japanese scenarios differ. The share of fossil energy decreases from 85% (2020) to 0-10% (REI, NIES) or 40-50% (RITE, IEEJ scenarios with CCS) in 2050. The share of renewable energies in the generated electricity mix rises from 20% in 2020 to 100%–(REI) or 40-70% for the other scenarios. The installation of renewable energies is limited because of land use restriction. If a massive expansion of renewable energies should be adopted, renewable energy sources would have to be installed in restricted areas such as forests or farmland.

In contrast to Germany, nuclear energy is also considered as a supporting energy carrier towards climate neutrality by most scenarios. In addition, final energy consumption from gas and oil remains for transportation or industries, including steel or chemical. The residual greenhouse gas emissions are compensated by using DAC.

In many Japanese scenarios, electrification is determined as a model result while some scenarios may consider electrification as an assumption. If marginal electricity costs are lower than the costs for other technology combinations such as gas + DAC or gasoline + DAC, electrification will tend to increase. Many scenarios show the share of electricity in final energy demand also increasing up to 40–50%, since the total final energy consumption is reduced by 2050.

**Germany**: In German scenarios, the share of renewable energies in primary energy rises to 95%, and to 100% in electricity production by 2045. Thus, compared to Japan, the installation of renewable energies is significantly higher. But to achieve this, massive additional capacities of on- and offshore wind power (174-250 GW) and PV (119-385 GW) are needed. The higher numbers consider the available potential for wind energy in Germany, but not the complete PV potential, because it does not include e.g. building-integrated and agri-PV.

The electricity supply-demand balance can be assured by all kinds of flexibility options and some 5-7% of gas (including $H_2$). Hydrogen from other countries and from electricity by offshore wind is a key option to reduce $CO_2$ in industry and transportation. Nuclear energy is not included in the model assumptions, because the German government decided on the nuclear phase-out to be completed by 2022.

## 6.3 Key technologies to fully reduce $CO_2$ emissions

This section relates to options used in the scenarios for fully reducing the energy-related GHG emissions. Particularly in the sectors agriculture, waste treatment, and some industrial processes it appears difficult, if not impossible, to fully reduce GHG emissions.

**Japan:** DAC (approximately 100-200 Mt-$CO_2$) and CCS are also considered key options to reduce $CO_2$ from e.g. gas power plant or furnace in those scenarios that still see a considerable share of fossil fuels in 2050, while some scenarios such as REI rely on hydrogen imports. However, it is uncertain how much $CO_2$ can be stored by CCS.

**Germany**: The import of zero-carbon fuels, such as green hydrogen and derived PtX fuels, is a key option to meet the overall final energy demand. Maintaining the electricity supply-demand balance depends on domestic flexibilities, domestic green hydrogen, and in some scenarios, limited net electricity imports. Nuclear power plants are generally assumed in the models to be phased out by 2022.

All German scenarios also consider technical sinks as an inevitable strategy. However, the envisaged quantities are relatively low. For about 5% of remaining GHG emissions, mostly from the non-energy sectors, natural sinks, BECCS and DACCS are the most important options considered. Remarkably, the BDI puts emphasis on DACCS.

While the Japanese scenarios stress the need to consider various technologies (including nuclear energy) so as to ensure cost-efficiency and energy security, the German scenarios underscore that energy security can go along with positive economic effects and the impact of innovations, while phasing out nuclear and coal energy.

# 7. Shortcomings to achieving the net zero carbon target for 2050 in Japanese scenarios and enhanced or new strategies

Author: The Institute of Energy Economics, Japan

## 7.1 Gaps

All Japanese scenarios assume achieving carbon neutrality in Japan by 2050. And all models focus only on Japan. Hence, none of the models shows any implication of the 1.5-degree-reduction-target that must be achieved worldwide. In order to discuss the possibility to reach the 1.5-degree, it is necessary to develop a worldwide model assessment. Although it is difficult to discuss the worldwide potential to meet the 1.5-degree-target based exclusively on this scenario comparison, to achieve the results predicted by the models, it is important to analyze the gap between ideal scenario results and reality.

### 7.1.1. Social acceptance for installation of nuclear and renewable energies

All Japanese scenarios consider either nuclear power plants or renewable energy as important power sources to achieve carbon neutrality. As for nuclear power plants, almost all scenarios model only with existing nuclear power plants or those that are already in the planning. Only RITE and IEEJ develop scenarios allowing new constructions. Although the scenarios show that new constructions potentially contribute to a reduction of total integration costs based on model analysis, cost-analysis considering safety measures should be carefully evaluated as German studies argue that the construction of new nuclear power plants in Germany is not cost-effective (DIW 2019). In addition to this, social acceptance regarding restarting or constructing nuclear power plants is a key issue to implementing these scenarios. Following the Fukushima accident in 2011, many residents are opposed to restart nuclear power plants because of safety concerns.

The issue is raised not only for nuclear power but also for renewable energies. Many scenarios show a massive installation of renewable energies to achieve carbon neutrality. As a result, the percentage of renewable energies in generated electricity in 2050 is approximately 40-100%. However, for achieving this capacity, PV systems or wind turbines must be installed in restricted areas such as forests or farmland. Even for offshore wind energy systems, wind turbines must be installed in the near shore area which has a negative effect on the coastal landscape or is restricted by the fishery rights in that area. In Japan, fishers have a strong legal basis to refuse developments in areas covered by fishery rights based on the Fishery Act. For example, they have the right to claim losses caused by development changes and seek injunctions. Therefore, developing offshore wind energy in areas covered by fishery rights is impossible without the consent from the fishers.

### 7.1.2. Potential of $CO_2$ storage

Many Japanese scenarios assume utilizing CCS or DAC to capture $CO_2$ from power plants or industry plants such as furnaces. The scenarios set the upper limit of $CO_2$-capture-capacity at approximately > 1000 million t / year. The $CO_2$-storage requires large areas of land, but it is not clear, how big the $CO_2$-storage-potential on the Japanese territorial land or oversea is. If CCS or DAC could not be fully utilized as the scenarios show, more electricity from renewable energy or electrification is required and total energy system costs will increase. Thus, it should be noted that the feasibility of scenarios using CCS or DAC depends on the potential of $CO_2$ storage capacity.

### 7.1.3. Feasibility of massive installation of storage systems

The Japanese scenarios show that a massive installation of storage systems is required as renewable energies increase (>1000 GWh). Even if 10 kWh storage systems were installed in currently existing residential homes (290 GWh), the capacity cannot be satisfied with the required capacity to maintain hourly energy supply-demand balance. Moreover, materials shortages are also a concern in regards to lithium. Hence, not only economic feasibility but also the material supply risks of storage systems should be taken into account.

## 7.2 Enhanced or new strategies to close the gap

Although many Japanese scenarios draw pictures of carbon neutrality by 2050 using back-casting models, there is no scenario that convincingly proves the feasibility of climate neutrality by 2050. As described above, all scenarios have some kind of critical issue such as social acceptance or the potential of $CO_2$-storage. If a specific technology is excluded in the scenario assumption, the number of possible strategies to achieve carbon neutrality is also limited. Hence, it is important to seek various low emission technologies not only renewable energies, but also include nuclear power, CCS, DAC and ammonia power plants. To come closer to the pictures drawn by the scenarios, the following strategies are considered important.

### 7.2.1 Establishing a process to gain consensus from stakeholders

Given the estimated increase of nuclear power plants or massive installations of renewable energies in order to reach carbon neutrality, the need of social consensus will increase respectively. However, a concrete process to gain consensus from stakeholders or local residents has not been sufficiently established. Especially for PV systems or onshore wind, there are no specific rules on how to take the opinions of stakeholders or local residents into consideration. Hence, it is important for the feasibility of scenarios to consider the question of how to reach consensus among stakeholders and/or local residents to enable the massive installation of renewable energies or nuclear power plants.

### 7.2.2 Consistency between local spatial planning and carbon neutrality

Up to now, some of the PV systems or onshore wind turbines — for instance, those in forests — proved to have negative effects on the local environment and wildlife / biodiversity. According to a report by the Japanese Forestry Agency, the total area of deforestation attributable to the installation of PV systems is more than 90 $km^2$, which is equivalent to an installed PV power capacity of 6 GW (Japanese Forestry Agency, 2019). In the case of onshore wind energy systems, 56% of systems installed after 2004 were in forests or wilderness areas (MoE 2011). Given these facts, the Japanese government now considers spatial planning called “positive zoning” to determine those areas where only few or no negative effects on nature through the installations of photovoltaic (PV) systems and wind turbines are to be expected. Therefore, the expansion of renewable energies to the end of reaching carbon neutrality and the spatial planning that regulates the installation are in a trade-off relationship. For example, many scenarios implying renewable energy may have to be installed in restricted areas such as forests, but these areas are possibly excluded from positive zoning areas. Hence, it is essential for decision-makers who determine renewable energy targets to also take spatial planning into consideration. Moreover, it is also important to develop agri-PV by ensuring crop production and reducing the impact of landscape.

### 7.2.3 Assessing the impact of non-power sectors by carbon neutrality

Many current Japanese scenarios focus on the power sector. However, non-power sectors such as the industry sector and the transportation sector account for approximately 50% of total $CO_2$ emissions. It is thus important to also consider the non-power sector when aiming at carbon neutrality. Hence, future scenario analysis should also include key strategies for non-power sectors to approach carbon neutrality.

# 8. Shortcomings to achieving the net zero carbon target for 2045 in German scenarios and enhanced or new strategies

Author: Wuppertal Institute for Climate, Environment and Energy

The German scenarios presented in Chapter 5 all underscore the technical feasibility of achieving carbon neutrality by 2045 while presenting somewhat different pathways with varying degrees of energy demand reduction, electrification, renewable energies, the use of hydrogen and hydrogen-based synthetic fuels, and carbon sinks.

The basic strategies in the German representative scenarios are comparable and can be summarized as follows.

- the nuclear phase-out will be completed in 2022;
- coal-fired power generation must be phased out well ahead of 2038, ideally by 2030;
- the expansion of renewable energies and, above all, renewable power generation is massively accelerated;
- the rate of energetic refurbishment of the building stock is increased considerably, and *deep renovation* must be achieved during retrofit processes; energy efficiency is also increased in the industry sector, and some potentials of sustainable transport are harnessed;
- decarbonization of the transport, building and industry sectors takes place as far as technically and economically possible through direct (green) electrification
- the expansion of the hydrogen economy – with increasing proportions of imports (hydrogen and PtX) – plays an important role mainly after 2030.

Indeed, numerous scenarios also from other institutes, even with different technical and energy policy positions, nevertheless reflect *a broad scientific consensus on the technical feasibility* of climate neutrality in Germany by 2045 with regard to the basic strategies. In all scenarios, the phase out of nuclear energy in 2022 is assumed to be safely manageable. The basic availability of less risky climate protection technologies to achieve climate neutrality by 2045 is no longer in question in any scenario. Instead, the discussion focuses on fundamental questions about the socio-economic relevance scenarios and the tension between scenarios, levels of ambition and implementation, which will be addressed below. In this respect, various shortcomings can be identified that could be resolved by a number of additional strategies that should be considered in prospective studies. Through a stronger analysis of the necessary policies and these additional strategies, the reliability of the scenarios and the confidence that carbon neutrality will be achieved in practice by 2045 can be enhanced. They will make the rationale of highly ambitious climate mitigation policies more understandable and acceptable for the public. On this background and backed with additional analysis, it might be possible to achieve carbon neutrality even faster than by 2045, eventually by around 2035.

## 8.1 Shortcomings of technology-focused German scenarios

The selected German scenarios are strongly focused on *energy-related strategies* and the associated *technical feasibility* of decarbonization. A special focus is on the electricity market and on the differentiated analysis of a renewable electricity supply. This is undoubtedly a crucial pillar of ambitious climate protection policy, but the essential socio-economic aspects are only addressed in the BDI study, while the behavioral aspects (e.g. rebound and growth effects or the opposite, more sustainable consumption patterns) of an energy transition are not touched upon at all or only marginally in all scenarios, with the exception of the UBA study.

### 8.1.1. Energy efficiency first

While **energy efficiency** plays an important role in all scenarios to reduce the overall demand. But in most scenarios, the existing potentials, particularly in the transportation and building sectors, but also in the industry sector, are not fully exploited. Only the GreenSupreme scenario of the UBA takes a larger potential into consideration. The combination of **material efficiency and circular economy** strategies is also only partially pursued, e.g. by the UBA study and to a certain degree by the BDI study. Without a policy integration of climate and resource protection, the strategy is biased towards supply-focused electrification strategies.

### 8.1.2 Socio-economic aspects

While technical feasibility is a crucial prerequisite of transformative paths to decarbonization, economic optimization of possible pathways is also important. However, in the selected studies, the simulation of **macroeconomic effects** is missing or only carried out in the first steps. Moreover, challenges such as area restrictions related to the estimated intensive installation of renewable power plants and the importance of **social acceptance** are not fully anticipated in most studies. The same holds true for material restrictions related to PV and wind power (silicon, rare earths). With regard to social acceptance, **distributional effects** for households, companies and regions also deserve closer attention in order to devise the necessary narratives of a just transition; they are only analyzed to some degree in the BDI study. In this context, rebound and lifestyle effects (values, behaviour), sufficiency policies and issues of change management (innovation/exnovation) also need to be shed light on. To date, only the UBA study includes some of these aspects.

### 8.1.3 Policies for the actual implementation of the strategies

Most scenario studies conclude with a list of policies that are perceived as being able to reach the calculated scenario results. However, usually the studies do not directly model the impact of concrete policy instruments and packages, which are needed to enable and incentivize both the technical and behavioral actions needed for the transition.

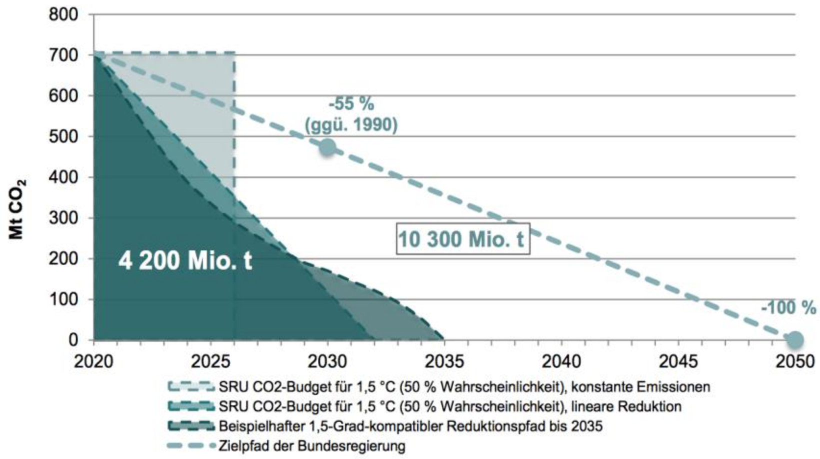
### 8.1.4 The ambiguous role of hydrogen

While the importance of including significant amounts of hydrogen and hydrogen-based synthetic fuels is common ground among the studies, only little is said about the challenges that come along with it: Neither do the scenarios present detailed concepts on the necessary infrastructure, nor do they thoroughly discuss possible target conflicts concerning (domestic and) imported hydrogen (e.g. perspectives of exporting countries/global competition/international standards for certifying green hydrogen/synfuels).

### 8.1.5 Compliance with international commitments: how to reach the 1,5°C-target

Finally, the scenarios fail to explicitly discuss whether the ambition level and the strategies they provide suffice to achieve the internationally agreed 1,5°C-target. The studies by Agora, dena, and BDI only focus on the analysis of if and how the carbon neutrality target for 2045 could be achieved. Applying the aforementioned budget approach (cf. chapter 5), the Wuppertal Institute showed that the global $CO_2$ budget compatible with the targets of the Paris agreement demands for even more ambitious targets: As the graphic below illustrates, Germany would have to reach climate-neutrality as early as 2035, because the remaining $CO_2$-budget of 4,200 tons would have been consumed by then.

*Figure 17: Exemplary Emission Reduction path according to a German 1.5°C budget*




Source: Wuppertal Institute 2020; based on SRU 2020

It must be emphasized that the study of the Wuppertal Institute as of today (March 2022) still is an initial illustration for Germany that has not yet been backed-up by a complete scenario analysis. However, it highlights that Germany's contribution to a global strategy "keeping 1.5 degrees within reach" requires a tremendous additional effort. Nevertheless, the authors of the study sum up: "A climate-neutral energy system by 2035 is very ambitious, but fundamentally feasible if all strategies that are possible from today's perspective are joined" (Wuppertal Institute 2020[13]).

Thus, the key challenge remains how the technical focused strategies in the existing highly ambitious scenarios must and can be combined with stronger policies or other policy integration options, e.g. with sufficiency, circular economy/material efficiency, and stronger energy efficiency policies, to reach carbon neutrality ideally in 2035.[14] It should therefore be examined whether and to what extent the existing energy-related scenarios can be linked and supplemented with corresponding quantified sub-scenarios, in order to establish robust strategies for policy advice (see chapter 9).

## 8.2 Enhanced or new strategies to close the gaps

Corresponding to the aforementioned shortcomings, the following strategies are suggested to be included in future scenarios and connected analyses: (1) the integration of circular economy strategies, (2) the consideration of sufficiency policies, lifestyle changes, just transition and public/social acceptance, and (3) the inclusion of policy integration through sector-coupling.

### 8.2.1 Integration of circular economy (CE) strategies

The integration of circular economy strategies into climate protection policies unfolds significant synergies related to material and energy efficiency: Including the use of raw materials into the scenario analysis would also help to avoid problem shifting to critical metals and unsustainable extraction facilities. The technical potentials do exist, but every

[13] https://wupperinst.org/a/wi/a/s/ad/5169

[14] A so called global „Societal Transformation Scenario (STS)"has been published recently: „The...results for the STS show a large decline in energy demand in the Global North and a reduction of global GHG emissions of roughly 50% from 2020 to 2030 and a further 22% (12.7 Gt $C0_2$eq) by 2050...The cumulative $CO_2$ emissions remain within the carbon budget that gives us a 2/3 chance to staying within the temperatur increase of 1.5° C." (p.10). The assumed redistribution of wealth, power, consumption and production might be utopian but it presents food for thought to analyze opportunities and risks of including sufficiency policies into technically focussed scenarios. https://www.boell.de/sites/default/files/2020-12/A_Societal_Transformation_Scenario_for_Staying_Below_1.5C.pdf?dimension1=division_iup

kilowatt hour avoided through energy and material efficiency would facilitate the expansion of renewable energy generation and particularly help to reduce the immense implementation problems (e.g. space requirements, network expansion, resource consumption, import requirements, acceptance).[15]

### 8.2.2 Consideration of sufficiency policies, lifestyle changes

To ensure a comprehensive analysis of the pathway towards climate-neutrality, socio-economic aspects need to be considered. This includes values, change-management, innovation and exnovation strategies. Most important societal topics of socio-economic transformation (e.g. behaviour shifts, societal tipping points, mobility patterns, floor space, living comfort, eating habits, reducing meat/dairy products, food waste, etc.) sometimes cannot easily be included into existing modelling approaches. Also, a transformation of the agricultural sector with fewer livestock, more organic farming, an increase of non-productive areas and biodiversity should be considered. The risk that a scenario-based "proof" of the technical feasibility leads to wishful thinking and unrealistic target-setting should be avoided. For example, rebound-, the inertia of lifestyles, or growth-effects are a reality and they should be anticipated into scenario assumptions and procedures as much as possible.

### 8.2.3 "Just transition" and citizen participation

The socio-economic transformation and enormous economic structural change on the way to carbon neutrality makes it imperative to anticipate possible detrimental or supporting distribution and welfare effects. For example, carbon pricing will have a regressive impact on households and can induce carbon-leakage if not supported by compensation measures. Also, wind power and huge ground-mounted PV might face strong local opposition. But refunding a part of the revenues from carbon pricing, citizens participation, financing and local benefit sharing can increase public acceptance for the transformation.

[15] Compare Acatech (2021), Circular Economy Roadmap for Germany acatech/Circular Economy Initiative Deutschland/SYSTEMIQ (Eds.) Update December 2021.

Thus, *just transition* should be a basic focus of scenario-related analysis and it should be directly included into scenario assumptions and strategies.
In Germany, for example, the coal regions and – foreseeable – the automotive sectors are focal points of structural change. Thus, macro-economic analyses are of utmost importance, but they should be combined with calculating net-effects e.g. for jobs, added value, income and budgets referring to regional hotspots of economic structural change.

#### 8.2.4 Analysis of policies and policy integration, and their inclusion in the modelling

Finally, the analysis of policies, which are needed to implement both, the technical and behavioral actions needed for the transition, need to be included in the models to offer a more realistic view on whether and how targets can be achieved. In addition, policy integration (e.g. heading for a sustainable and just mobility not only relying on electrification or integrating the housing and the overall city planning) allows for a comprehensive view on the endeavor of reaching climate-neutrality. For example, through the integration of comprehensive policies in the scenario strategies, the potential of technical (e.g. prefabricated buildings), economic (e.g. overcoming split incentives), institutional innovation (e.g. one-stop-shops for targeted advice and support, decentralized heat networks) and social goals (e.g. affordable housing for low income families) can be addressed in comprehensive policy packages.

As mentioned above, probably the most ambitious targets of the scenario-based policies in Germany refer to the heating sector and the retrofit of the existing building stock. Achieving a doubling or even a tripling of the retrofit rate and a rapidly growing share of renewable energy for heating systems implies a comprehensive policy mix to drive complex system changes, not only in single buildings, but also in neighbourhoods and districts.

# 9. Overall conclusion

In this study, a comparative analysis of recent long-term scenarios to reach climate-neutrality in Germany by 2045 and Japan by 2050, respectively, was conducted. The objective was to identify, which strategic technological options are being considered and what transferable lessons can be learned. The analysis revealed some similarities in the approaches as well as divergent assessments (cf. chapter 6). Also, shortcomings of prevailing scenarios and opportunities to use scenario comparisons as an instrument for social learning were identified. Following are some general conclusions which can be derived:

## 9.1 Strategic technological options

For both countries, the scenarios underscored the importance of energy efficiency and of a forced market introduction of renewable energies. The shift towards a more climate-neutral energy mix is supported by expanded electrification of the building and transport sector and the increased use of ‘green’ or at least low-carbon hydrogen and synthetic fuels. Finally, both countries also consider technical carbon sinks to compensate residual (“hard to abate”) greenhouse gas emissions. Comparing the strategic *technology options* of German and Japanese scenarios three important differences can be summarized:

(1) The amount of energy reduction

The reduction of primary and final energy by 2045/2050 in German scenarios seems to be more pronounced than in Japanese scenarios. These differences should be further explained e.g. how far this impact is related to more ambitious energy efficiency improvements or pronounced acceleration of renewable energy sources or different patterns of structural change. As the UBA GreenSupreme scenario demonstrates, also within the selected range of German scenarios there are apparent differences concerning the implementation of the “Energy Efficiency First” principle of the IEA.

(2) Energy mix: Interpretation of the term *climate-neutral* technology

While Germany aims at a share of renewable energies of almost 100%, including the use of 100% green hydrogen/synfuels by 2045, the renewable energy share in Japanese scenarios varies from only 40 to 100% in Japan (until 2050). Although hydrogen in Japan is also considered as an important strategic pillar of decarbonization, the focus is not necessarily on green hydrogen, due to a lower share of electricity from renewable sources. Another reason might be that due to international pipelines for hydrogen supply are not easily available in Japan. Additionally, the selected Japanese scenarios also include nuclear energy and the continued use of fossil energy with CCS technology. The feasibility of these technologies depends on how much potentials for CCS is available, how far renewable energy costs and storage costs will decrease and whether social acceptance of nuclear power plants and CCS can be achieved.

(3) Residual emissions and removals:

The German scenarios target at full decarbonization of the energy sector, fewer residual emissions from the non-energy sectors and relying both on technical and natural sinks. The majority of Japanese scenarios – due to a larger residual share of fossil fuels – result in higher remaining greenhouse gas emissions, including those from the energy sector, and therefore need to strongly rely on CCS, including DACCS (cf Chapters 4, 5, 6).

## 9.2 Improved scenario approaches

But there are also shortcomings in both countries regarding the methodology and the use of scenario analyses as well as in policy mixes to effectively guide the fundamental structural changes and the transition strategies elaborated by the scenarios.

It seems to be worthwhile to address them by future research cooperation on scenarios.

In brief the recommendations can be summarized as follows:

- Operationalize the principle “Energy Efficiency First” (IEA) and conduct a comprehensive assessment of energy efficiency potentials, costs and co-benefits in all sectors
- Prioritize direct electrification (where feasible) instead of gas-based pathways, due to the higher energy efficiency, by a factor 3 to 5, and hence lower needs to expand low-carbon power supply
- Develop integrated energy and material efficiency approaches by combining climate protection and Circular Economy (CE) strategies
- Combine technically focused strategies with elements of sufficiency strategies, including enabling strategies towards sustainable production and consumption
- Consider barriers and policies to achieve social acceptance, by reflecting also area restrictions, possible problem shifting (e.g. concerning critical metals) and nature conservation
- Integrate socio-economic distributional aspects dealing with just transition, reflecting regional structural change, resilience, citizen participation and citizen financing
- Focus on sector coupling and policy integration, e.g. concerning transportation (e.g. e-mobility) and buildings (e.g. heat pumps, district heating/cooling)
- Continue efforts towards the market introduction of risk-minimizing, low-carbon technologies to avoid lock-in effects into high-risk technological pathways (e.g. coal or nuclear energy)

It is evident that the up-take of these recommendations must be considered and evaluated in an international and geostrategic setting. This setting might currently be perceived only as a threat (see outlook), but it would be wise to recognize the long-term opportunities as well. This general recommendation can be summarized as follows: Assess the opportunities of long-term global dynamics, innovations and competition of transformative strategies and technologies to carbon neutrality. Global technical and market developments might change the optimum energy mix in the direction of rapid climate neutrality, more energy security, further cost degression of low-risk technologies and less resource conflicts on fossil fuels.

## 9.3 Interlinkages between scenario modelling and policies

In both countries there is a close exchange between the scenario-community (e.g. think tanks) and politics. In the past, e.g. in Germany, political targets regarding GHG emissions reductions were often justified by scenario based back-casting approaches. Accordingly, the GHG reduction targets (2050/2045) defined by the governments appeared more based on a prevailing perception of the current government what might be *"feasible"*[16] than on the internationally agreed GHG reduction targets that are deemed *necessary*: limiting global warming to well below 2°C, if possible to 1.5°C. Thus, in order to develop comprehensive, independent and research-based climate policy approaches, two prerequisites need to be taken into account: 1) global necessities and 2) national possibilities.

### 9.3.1 Global necessities

IPCC in particular, represents a benchmark for national climate mitigation policies based on the latest international scientific insights. According to the budget approach, "what is necessary" requires a normatively based answer to the question of an appropriate and responsible national contribution to global climate protection. Thus, the ambition level of national climate policies and the back-casting target year of decarbonization scenarios should ideally be in line with global targets and agreements, such as the Paris Agreement 2015.

[16] E.g. the Agora study, the only available scenario prospecting climate-neutrality until 2045 at the time of the revision of the German climate protection law in 2021, can be said to have strongly influenced the political decisions.

### 9.3.2 National possibilities

While taking into account the global necessities, it is also indispensable to consider the national possibilities of ambitious GHG emissions reduction targets. The question on national possibilities cannot solely be answered by emphasizing the technological feasibility. Instead, scientific knowledge, political majorities, social acceptance and economic interests are key factors that need to be reflected in national climate policies. To this end, it is of utmost importance that the scenarios provide an analysis of socio-economic aspects as well. Yet, scenarios also need to consider that policy is able to shape national possibilities, e.g. by accelerating technology implementation and learning, and by measures to increase acceptance. Only if the important role of science is acknowledged, scenarios can significantly contribute to promising climate policies.

### 9.3.3 Strengthening the supporting role of science - scenario based stakeholder dialogues

The future is uncertain and the uncertainty increases when decisions on decarbonization strategies for the target year 2045/2050 have to be taken today by majority votes and consensus. Scenarios can be a powerful instrument of consensus building not only within the research community or between research and policy, but also related to the interests of different stakeholders and the broad public.

In Germany, there are some successful processes showing how scenarios contributed to consensus building on climate protection targets and a consensus-oriented formulation of the climate law in the state of North-Rhine Westfalia (NRW). [17] Furthermore, there are first positive experiences by establishing citizens assemblies [18] on climate policy in Germany, which were supported by scenario-based research. The integration of civil society actors that is enabled in such formats and processes can be evaluated as an important prerequisite of broader social acceptance.

[17] e.g. Schepelmann (2018)

[18] https://www.buergerrat.de/en/news/climate-assembly-in-germany/

### 9.3.4 International cooperation

Against the background of international competitiveness, a pivotal role can also be attributed to international cooperation, e.g. bilaterally between Japan and Germany or in a multinational context like the EU, the G7 or the G20. Synchronous and mutually reinforcing activities worldwide can help to increase the public support for even more vigorous climate policies at the national level.

Substantial and coordinated steps forward towards climate neutrality in Japan and Germany could induce important impulses to stimulate modernization, innovation and investment dynamics worldwide, putting the "well below two degrees" statement of the Paris declaration into reach.

## 9.4 A bright or a frightening outlook?

At the time of writing and finalizing this study (March 2022), the invasion of Ukraine by the Russian army has already caused endless human suffering and victims. The current expectation is that the end of the war and its catastrophic consequences are not yet in sight. It is likely that not only the entire geopolitical structure and the balance of power will change, but that the global energy system and climate policy will also be massively affected. So, does this war of aggression change everything for the energy world and the energy futures outlined above for Germany and Japan? One thing is certain: the perception of energy import dependency will change fundamentally, not only in Europe and Germany, but worldwide. Too much dependence on fossil fuels obviously affects peace and freedom, so it must be reduced as quickly as possible and, in the future, reduced to zero, not just because of climate protection, but for minimizing geostrategic conflicts. Kilowatt hours saved or gained from sun and wind do not cause or finance wars. For example, Germany's dependence on Russia for imports of 55% for natural gas, 45% for coal and 34% for oil is extremely dangerous for Germany and indispensable for Russia's military apparatus. But the 15 nuclear power plants and the 55% share of nuclear power in the Ukraine are a recognizable high risk as well, which should be reduced as quickly as possible after the end of the war, hopefully soon. Minimizing all risks connected with the domestic use of energy sources and the interdependent risks of all imported energy for the exporting and the importing countries should be taken much more into the research focus of long-term scenario approaches than in the past.

So, is everything changing? It is possible that climate protection will be pushed into the background again by the war. But it is also possible that there will be a growing recognition that energy efficiency and renewables are possible "freedom technologies" (as the German Minister of Finance called them) because they reduce conflicts about fossil fuels and other risky energy technologies, thereby minimizing potentially catastrophic life risks. In this respect, many options such as energy efficiency and renewables will be solutions for both climate action and improving energy security – a win-win situation. Nevertheless, a general risk check is required for the key energy transition and climate protection strategies and paths (Fischedick 2022). This also applies to conceivable new import dependencies in a globalized hydrogen economy or for PV panels.

It seems that bilateral research between Japan and Germany and within the GJETC is confronted with many new research topics, which should be addressed by intensified cooperation.

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