令和４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に係る調査

報　告　書

2023 年 3 月

一般財団法人日本エネルギー経済研究所

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第 1 章　日独エネルギー変革評議会の運営

1.1 背景

2020 年 10 月、日本は 2050 年のカーボンニュートラルの実現を目指すことを表明した。2021 年 10 月に閣議決定された第 6 次エネルギー基本計画では、2030 年度の温室効果ガス排出割合を 46%削減する目標の実現に向けたエネルギー政策の道筋を示すべく、政策対応をまとめている。2050 年のカーボンニュートラルの実現はいうまでもなく野心的な目標である。我が国の実現に向けた道筋の議論や取組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。

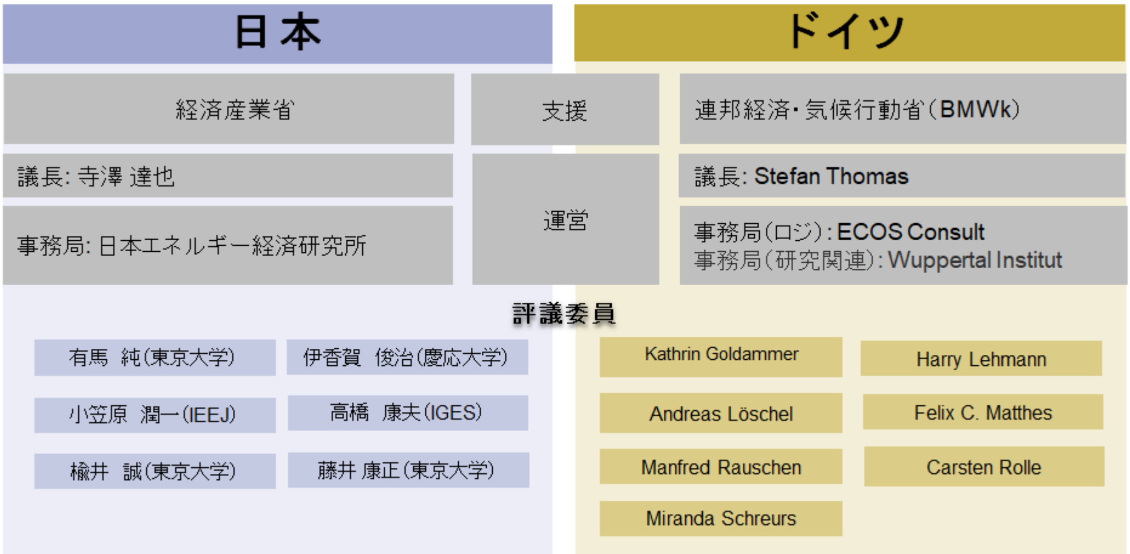
ドイツでは 2010 年に中長期エネルギー供給の在り方を示した「エネルギー・コンセプト」を決定し、現在は、省エネルギーと再生可能エネルギーの利用拡大を中心にして 2045 年までにカーボンニュートラルを達成するという目標を掲げ、エネルギー転換に取り組んでいる。両国において立場の違いはあるが、共にエネルギー転換に取り組むドイツと二国間協力を進めるべく、資源エネルギー庁は、2016 年に日本及びドイツのエネルギー専門家からなる日独エネルギー変革評議会（日独評議会）を設置し、再生可能エネルギー・省エネルギー等の両国で共通す る政策課題を中心に議論を深め、日本のエネルギー政策を企画・立案するうえで必要な情報調査・収集を行ってきた。

令和 3 年度の日独評議会では、鉄鋼産業の脱炭素化アプローチや車載用を含む蓄電池の利活用における課題、長期エネルギーシナリオ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、具体的には日独ともに課題を抱える膨大な数の建物の脱炭素化や、脱炭素化することが難しい産業（例えば化学産業）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

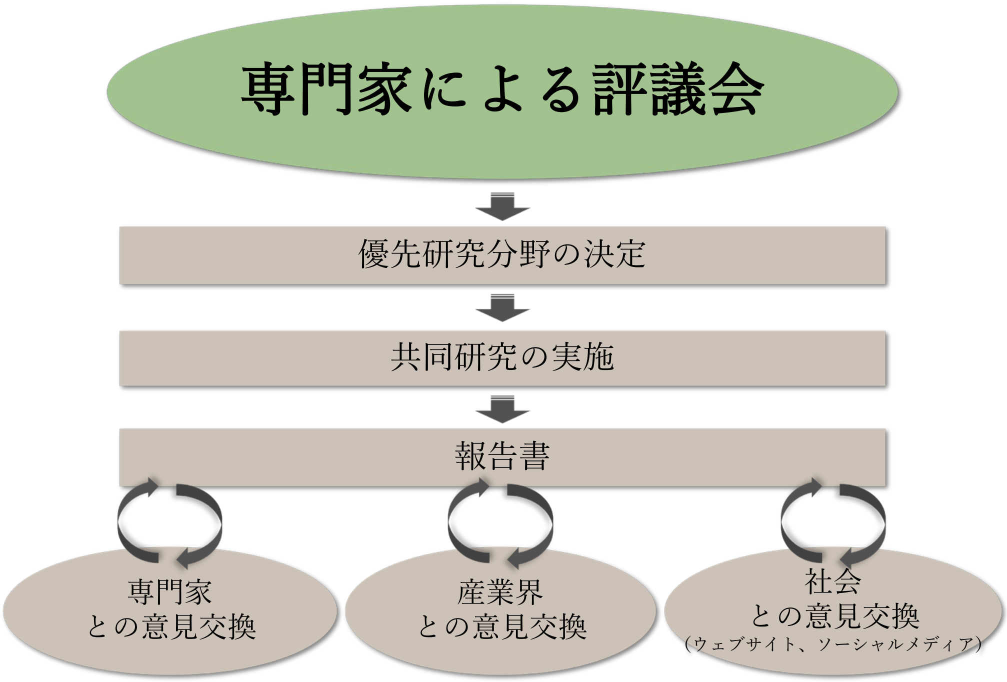
共同議長	
寺澤　達也	日本エネルギー経済研究所
Stefan Thomas	Wuppatal Institute for Climate, Environment and Energy
評議委員	
有馬　純	東京大学
伊香賀　俊治	慶応大学
小笠原　潤一	日本エネルギー経済研究所
高橋　康夫	地球環境戦略研究機関
楡井　誠	東京大学
藤井　康正	東京大学
Kathrin Goldammer	Reiner Lemoine Institute
Harry Lehmann	PTX Lab – Lausitz
Andreas Löschel	University of Münster
Felix C.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

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

2022 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　2022 年度の活動実績

	開催時期	内容
ウェビナー	2022 年 11 月	2021 年度事業の成果報告 ロシア/ウクライナ戦争の影響の議論
評議会（その 1）	2021 年 11 月	2022 年度研究計画の議論 ロシア/ウクライナ戦争の影響の議論
ウェビナー	2021 年 12 月	COP27 の評価 エネルギー転換の加速の議論
評議会（その 2）	2022 年 3 月	研究成果の議論 産業界（建築）との意見交換

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、「建物の脱炭素化」「エネルギー多消費産業の脱炭素化 – 石油化学 -」「廃熱利用」「化石燃料の脱炭素化」の 4 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。

研究は日独が共同で実施したほか、評議会における議論の結果も反映している。

建物の脱炭素化戦略

（Strategies, concepts and measures for decarbonizing the building stock by 2045/50）

いうまでもなく、カーボンニュートラル（CN）の実現に向けては建物の脱炭素化が不可欠である。しかしその寿命が長いことから、住宅用と非住宅用を問わず、現存する建物の多くが脱炭素目標の 2045 年（ドイツ）や 2050 年（日本）を超えて存在し続けることになる。このとき、脱炭素性能を備えていない建物を全て建て替えることは、それに要する膨大な量の資源や費用の点から現実的でなく、したがって既築建物を如何に脱炭素化していくかが極めて重要となる。既築の脱炭素化に向けては規制の強化や断熱性能の向上、機器の高効率化、太陽光発電の設置、それらを統合したエネルギー管理など様々な取り組みが進んでいる。

また従来の取り組みの多くは建物の運用時の CO2 排出を削減するものであったが、現在は建物の素材の脱炭素化を如何に進めるかという議論が広がっている。例えばコンクリートや鉄骨はその製造や輸送の際に CO2 を排出するが、CN の実現に向けてはこれらの排出もなくしていくことが求められる。

本テーマでは、両国の建築や建物でのエネルギー消費の実態を概観した上で、双方の建物の脱炭素化に向けた取り組みを比較分析し、それぞれの国に対する政策提言をまとめた。

エネルギー多消費産業の脱炭素化 －（石油）化学産業 -

（Roadmap for climate-neutral petrochemical production systems）

鉄鋼やセメント、（石油）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、またプラスチックやゴムなど製品の製造に炭素が必要であるなど、技術的あるいは経済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（石油）化学産業が存在し、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、（石油）化学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、（石油）化学産業は両国の産業で中核的な役割を果たしており、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。

本テーマでは、両国の（石油）化学産業を概観した上で、両国の脱炭素シナリオを比較分析し、それぞれの国に対する政策提言をまとめた。

廃熱利用

（The potential of waste heat usage in Germany and Japan）

カーボンニュートラルの実現に向けてはエネルギー効率を最大限にまで高める必要がある。廃熱は多くのプロセスで副産物として発生するものの、利用されることなく失われてしまうものが大部分である。これを回収・利用することによってエネルギー効率を更に高め、またエネルギーコストを引き下げることが可能である。

日独では既に様々な廃熱利用の拡大に向けた取り組みがされており、そうした事例から新たな気づきや学びを得ることができる。また例えば熱電発電については、商業利用に向けた技術開発の余地があり、両国が共同で研究を行う分野となり得る。こうした背景から本テーマでは、互いに援用可能性のある取り組み例を整理するとともに、共同での技術開発の課の可能性を探り、また廃熱利用の拡大に向けた提言を抽出した。

化石燃料の脱炭素化

（Comparing the basic strategies of Japan and Germany against the energy crisis while aiming to achieve their climate mitigation goal）

2022年2月に始まったロシアのウクライナ侵攻は国際エネルギー市場に大きな擾乱を巻き起こし、日本とドイツもその影響を大きく受けている。化石燃料資源大国ロシアからの輸出減少は物理的な供給不足のリスクを高め、化石燃料や電力の価格を大きく押し上げている。エネルギー危機に直面している日独は各々の国情に応じて様々な対策を講じているが、短期的には化石燃料投資を増やさざるを得ない事態となっている。足元の化石燃料投資と長期的な脱炭素目標とは整合しないようも見えるが、化石燃料を脱炭素利用する技術によ

ってこのジレンマを解消し得る。
本テーマでは、日本とドイツにおける目下のエネルギー危機への対応を整理し、長期的な脱炭素目標との整合に向けた考察を行った。

1.5 評議会等の記録
ここでは、2022 年度に開催した評議会やステークホルダー会議、ウェビナーの議事次第を開催時期の順に整理する。

① ウェビナーその 1（2022 年 11 月 9 日；オンライン）

16:30	Welcome by the GJETC Co-chairs
16:35	**Presentation of Results from the Studies conducted in 2021/2022** 1. 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? *Stefan Thomas (Wuppertal Institute) and Toshiya Okamura (Institute of Energy Economics Japan)* 2. Potential Roadmaps for Decarbonization of the Steel Sector *Thomas Adisorn (Wuppertal Institute) and Yoshikazu Kobayashi (Institute of Energy Economics Japan)* 3. Update on the Comparative Analysis of Long-Term Scenarios discussing Decarbonization Strategies in Japan and Germany in Times of Change *Lotte Nawothnig (Wuppertal Institute) and Hideaki Obane (Institute of Energy Economics Japan)* 4. Comment on BDI-Climate Path 2.0 and current Challenges for the Industry *Carsten Rolle (Federation of German Industries, (BDI))*
17:10	**Implications of the War in Ukraine for the German / EU and Japanese Energy Security and Climate Strategy** 5. Input (10 minutes): On Current Japanese Policy & Outlook after Ukraine War *Prof. Tatsuya Terazawa, Co-Chair of GJETC* 6. Input (10 minutes): On German/EU Policy & Outlook after Ukraine War *Prof. Peter Hennicke, Co-Chair of GJETC*

	7. Short comments *Prof. Jun Arima, Japanese Council Member (3 minutes)* *Felix Matthes, German Council Member (3 minutes)*
17:35	Discussion
17:50	Closing remarks

* 時刻は日本時間

② 評議会その 1（2022 年 11 月 28 日、29 日；オンライン）

1 日目

17:00	Greeting address / video messages *Patrick Graichen, State Secretary, BMWK* *Izuru Kobayashi, Deputy Commissioner, ANRE/METI*
17:10	Words of welcome *Peter Hennicke and Tatsuya Terazawa*
17:20	The GJETC's study program 2022 Study 1: Strategies, concepts and measures for decarbonising the building stock by 2045/50 (e.g. residential buildings) *Presentation of draft outline by Manfred Rauschen + Toshiyuki Kudo (IEEJ) 10 min* Discussion
18:00	*Break*
18:15	The GJETC's study program 2022 Study 2: Pathways to greenhouse gas neutrality for industrial sectors that are difficult to decarbonise: the petrochemical/chemical sector *Presentation of draft outline by Clemens Schneider (Wuppertal Institute)/ Dr. Susumu Sakai (IAE) (10 min)* Discussion Topical Paper 1: Use of waste heat *Presentation of draft outline by Johanna Schilling (ECOS) (5 min)* Discussion

* 時刻は日本時間

２日目

17:00	Energy sovereignty and decarbonisation with a short- and long-term perspective *Tatsuya Terazawa, Peter Hennicke (each 10 min)* Key Question: ● What is the realistic pathway to reach the Net Zero in Germany, Japan, and worldwide, especially in the global South? ● How can we speed up energy efficiency and renewable energies? ● How important is the decarbonization of fossil energy? ● How to handle distribution effects of temporarily rising energy costs heading for just transition? *Miranda Schreurs, Andreas Löschel + Jun Arima, Yasumasa Fuji (each side 10 minutes max.)* Discussion
18:30	*Break*
18:45	Suggestions for Innovation Roundtable *Input: Johanna Schilling & Stefan Thomas (ECOS / WI) (20 min)* Discussion
19:15	Outlook / Coordination of Dates
19:30	Expression of thanks and closing remarks by the Co-Chairs *Peter Hennicke* *Tatsuya Terazawa*

* 時刻は日本時間

③ ウェビナーその２（2022 年 12 月 9 日；オンライン）

16:30	Welcome by the GJETC Co-chairs *Tatsuya Terazawa, CEO & Chairman, Institute of Energy Economics, Japan (IEEJ)* *Stefan Thomas, Director, Division Energy, Transport and Climate Policy, Wuppertal Institute for Climate, Environment and Energy*
16:35	Insights of the COP 27: Experts Reporting on the Outcomes of the Conference in Sharm-El-Sheikh *Wolfgang Obergassel, Co-Director, Research Unit Global Climate Governance, Wuppertal Institute for Climate, Environment and Energy* *Takahiko Tagami, Senior Coordinator, Climate Change and Energy*

	Efficiency Unit, Institute of Energy Economics, Japan (IEEJ)
17:00	Panel Discussion: How can cooperation between Japan and Germany contribute to accelerating international climate mitigation and energy transition efforts? *Moderation: Peter Hennicke, Principal Advisor of the GJETC* *Stefan Thomas, German Co - Chair of the GJETC, Wuppertal Institute for Climate, Environment and Energy* *Takahiko Tagami, Senior Coordinator, Climate Change and Energy Efficiency Unit* *Institute of Energy Economics, Japan (IEEJ), Yasuo Takahashi, GJETC Council Member, Institute for Global Environmental Strategies (IGES)* *Kathrin Goldammer, GJETC Council Member, Reiner Lemoine Institute*
17:40	Closing Remarks from the Co-Chairs
17:50	Outlook on Upcoming GJETC Studies and Events

* 時刻は日本時間

④　評議会その 2（2023 年 3 月 2 日、3 日；対面）

1 日目

11:00	Greeting address / video messages *Izuru Kobayashi, Deputy Commissioner, ANRE Agency for Natural Resources and Energy, METI* *Jennifer Morgan, Secretary of State, Federal Foreign Office*
11:10	Words of welcome *Tatsuya Terazawa and Stefan Thomas*
11:20	The GJETC's study program 2022 Study 1:　Strategies, concepts and measures for decarbonizing the building stock by 2045/50 *Presentation of study results by Toshiyuki Kudo (IEEJ) / Manfred Rauschen (30 min)* Discussion
12:30	Lunch break
13:30	The GJETC's study program 2022 Study 2: Pathways to greenhouse gas neutrality for industrial sectors that are difficult to decarbonize: the (petro)chemical sector

	Presentation of study results by Susumu Sakai (IAE) / Stefan Thomas (30 min) Discussion
14:45	*Coffee break*
15:00	Topical Paper: Waste heat utilization *Presentation of results by Johanna Schilling (ECOS) and Taro Kawamura (IAE) (20 min)* Discussion
15:45	Open discussion on current political topics *Input presentation: Peter Hennicke / Mr. Sakai (IAE)* Open discussion

* 時刻は日本時間

２日目

10:00	Study topics for 2023 for the GJETC *Presentation of possible study topics (shortlist) by Lotte Nawothnig (WI) and Ichiro Kutani (IEEJ) (15 min)* Discussion
11:30	Coffee break
11:45	Topic for the Innovation Roundtable 2023 *Presentation of possible topics (shortlist) by Stefan Thomas, Ichiro Kutani and Johanna Schilling (15 min)* Discussion
12:45	Lunch break
13:30	Conceptual Talk *Timeline for 2023* *Next stakeholder dialogue with young scientists* *General discussion on prospective developments of the GJETC (e.g., formats, content, guidelines)*
14:15	Closing remarks by the Co-Chairs *Stefan Thomas* *Tatsuya Terazawa*

* 時刻は日本時間

⑤ ステークホルダー会議（2023 年 3 月 3 日；対面）

15:30	Welcome
15:35	Closing the implementation gaps: Targets, visions and strategies of the building industry (construction and equipment) *Statement of Keidanren concerning Carbon Neutrality Action Plan (Hayato Sunaga, Senior Manager, Environment & Energy Policy Bureau, Head of Challenge Zero Promotion Office, Keidanren)* *Statement of BDI concerning Climate Paths 2.0 (Dr. Carsten Rolle, Head of Department, Energy and Climate Policy Federation of German Industries (BDI)*
15:50	Results of the GJETC study on decarbonizing the building stock *Manfred Rauschen, Oekozentrum NRW / Toshiyuki Kudo, IEEJ*
16:05	Dialogue 1: Decarbonization of the building stock *Chair: Johanna Schilling, ECOS* *Oral statements by selected participants (2-3 min. x 5) followed by free discussion including council members.* *1. Which policy framework is needed to effectively address existing buildings/houses, i.e., which policy instruments should be combined?* *2. Particularly, what kind of financial support (e.g., public investment programs) is needed to foster (major) renovation of the existing building stock?* *3. Should policy foster renovation or demolition and new build, and how to manage embedded carbon in both cases?*
16:50	Break
17:10	Dialogue 2: New build of zero-emission buildings/houses *Chair: Prof. Toshiharu Ikaga, Keio University* *Oral statements by selected participants (2-3 min. x 5) followed by free discussion including council members.* *1. Which policy framework is needed and effective to promote new build of zero-emission buildings/houses?* *2. How to reduce embedded carbon?*
17:55	Closing remarks of the GJETC co-chairs

* 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 4 つの研究テーマの成果を概説する。詳細は、付録 1 から付録 4 を参照されたい。

2.1 建物の脱炭素化戦略

2.1.1　背景と目的

日本とドイツの建築物から排出される二酸化炭素の量は全体排出量のおよそ 20～40%を占めている。当該分野への脱炭素化対策は、両国の温室効果ガス削減目標達成に大いに貢献するものとして、現在関連法規やルールの改定・新設、再エネ導入や木材使用促進等、脱炭素化に向けた取り組みが加速している。一方で、建築物は、元来その国土の広さや地理、自国を取り巻く自然環境、賦存する天然資源や入手可能な建築資材、連綿と受け継がれ根付いてきた生活習慣や文化的思想などに大きく影響を受けるため、両国の建築物自体の特徴や脱炭素化対策も、かような所与の条件を踏まえたものとなっている。本調査では、両国の建築物の特徴や、建築物に対する省エネ・脱炭素化に関わる法制度・施策を調査・分析し、脱炭素化対策における共通点・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　日独との建築物の特徴や諸政策

ドイツの建築物は、およそ 9 割を住宅が占め、そのうち 75%以上が戸建てまたは準戸建てとなっている。非住宅についてはその 6 割が役所等の公共施設が占める。ドイツの一人当たりの床面積平米数は 47.7 ㎡（2021 年）であり、1990 年ごろから大規模アパートや住宅が増加したことで当該数値は上昇、しかし 2010 年ごろから移民増加により同数値はほぼ横ばいで推移している。

建築年代別では、住宅の約 7 割が、最初の「断熱条例」が制定された 1979 年以前に建てられたもので、そのエネルギーの平均消費量は新築住宅と比べ約 5 倍と大きい。非住宅については、商業用またはレストランやホテルなどに使用される建築物の大部分が 1958 年以前に建設されたものである。建築物の改修率については一定数あるが、あくまで一般的な改修工事であり、エネルギー効率を高めることに特化したものは少ない。

建築資材としては、住宅についてはレンガ造りが主流だが、最近では木造建築のシェアが増加しており、2021 年では全体の約 2 割に達している。非住宅建築物では鉄筋コンクリートが主流だが、木造建築も増加傾向にあり、2021 年には全体の約 2 割に増加している。

ドイツ国内の住宅 1,890 万棟のうち、セントラルヒーティングシステムを備えているのは 81.8%で、その約半分の 40.5%が天然ガス焚き、29.8%が石油焚きである。

建物の断熱性を高めるとともに、建物で使用される暖房、冷房、その他の電気・電子機器の総合的な効率を高めることを目的とした多くの施策により、建物のエネルギー効率原単位は徐々に低減してきており、住宅のエネルギー経済効率は 166.6kWh/m^2/年（2020 年）、

非住宅のそれは 136.2 kWh/m²/年（2020 年）である。

日本の建築物については、その 7 割を住宅が占めている。戦後の深刻な住宅難に陥った経験から日本では新築建築が主流で、1950 年から 70 年に供給された多くの建築物は安価で早期竣工するものが多く、質はさほど重視されなかった。また、地震大国である日本では大地震が起こるたびに耐震基準を強化されてきた。1981 年に現行の耐震設計基準（新基準）が制定されたが、1980 年以前に建てられた住宅には遡及して適用されないことから、現状約 1,000 万戸の住宅が新耐震基準に合致していない。省エネ基準については、1979 年の省エネ法制定後、省エネ基準が順次強化されてきた。しかし義務ではなかったことから、住宅ストックの 9 割が現行の省エネ基準に適合していない。

日本の建築物は伝統的に木造建築が主流だったが、大型建築物については耐久性や耐火性の観点で鉄筋コンクリートの使用が進んだ。

日本ではエネルギーは主に冷暖房、調理、給湯、照明・家電に使われており、建築物や家電所有の増加、デジタル化により、照明・家電でのエネルギー消費が伸びている。また欧米に比べると、日本では給湯でのエネルギー消費が多い。日本は部分間欠空調が主流であることから暖房需要が少なく、一方で入浴文化から給湯でのエネルギー消費が多い。また、家電の普及による電力需要増で電気料金が値上がりしていることから、現在省エネ家電が広く選ばれるようになっている。

建築物のエネルギー経済効率については、戦後復興に伴う GDP 成長と雁行する形で悪化傾向にあったが、家電を中心とするトップランナー制度の導入や省エネ法の改正により、1995 年ごろから経済成長とは切り離され改善に転じている。例えば家庭部門では、1980 年から 2020 年の間で、日本の一人当たりの GDP は 77%増加したが、住宅のエネルギー経済効率の増加は 3.8%にとどまっている。業務部門についても、同期間の GDP は 90%増加する一方で、非住宅のエネルギー経済効率は 29%の増加にとどまっている。

2.1.3　建築物の脱炭素化に向けた政策

2015 年のパリ協定合意を踏まえ、ドイツでは自国の気候保護目標及び EU の目標規定の達成を目的に、連邦気候保護法が 2019 年 12 月に制定された。その後同法は 2021 年に改正され、2030 年までの排出削減目標を 1990 年比 55%減から 65%減に引き上げたほか、新たに 2040 年までに少なくとも 88%の削減を中間目標として定め、カーボンニュートラルの達成を 2050 年から 2045 年に前倒しした。また、2030 年までのエネルギー、産業、運輸、建築の各セクター目標も強化され、建築部門では、2030 年迄に年間 CO2 排出量を 2020 年比で 5,100 万トン（43%）削減することが明記された。

表 2.1-1　部門別の CO2 排出量目標

Annual emission budgets in million 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

出所：連邦気候保護法、2021 年

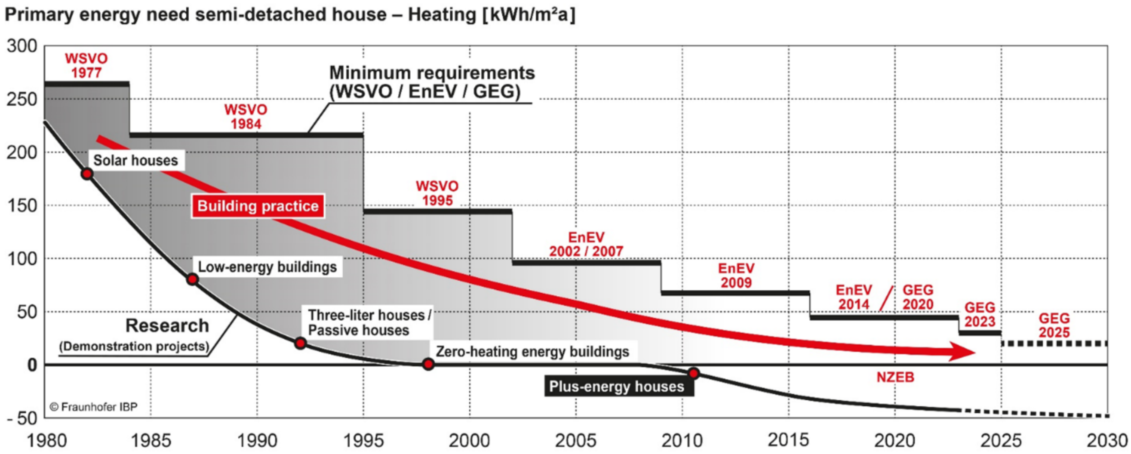
建築物の省エネ対策については、1970 年代の石油危機を契機とした断熱条例制定に始まり、その後関連法規が別々に制定・改定されるなか、煩雑な手続きの簡素化と政策強化を目的に、建築物省エネ法、建築物省エネ令、再生可能エネルギー熱法を統合する形で 2020 年 11 月に建築物エネルギー法（GEG）が成立した。同法では、新築・既存建築物の総エネルギー需要や断熱性能、冷暖房への再生可能エネルギー利用に関する要件を定められ、特に新築建築物の一次エネルギー消費量は、参照建築物の 75%に抑えることが義務付けられた。また、建築物の販売・賃貸の際に、建物エネルギー性能証明書（EPC）の取得・提示を義務化した。当該証明書は設計・仕様からエネルギー性能を計算するための需要証明書と、実際の消費エネルギー量に基づいて性能を把握する消費証明書に分かれる。証明書には、最終エネルギー需要や、A＋からＨの 9 等級で表された住宅のエネルギー効率等級が表示される。

2021 年の建築分野の温室効果ガス（GHG）排出量が、連邦気候保護法で設定された同年での分野別年間許容値を超過し（許容値：112 MtCO2e、実績値：115 MtCO2e)、2030 年のセクター目標達成が難しくなったことを受け、2022 年に GEG が改正された。当該改正では、2023 年以降の新築建築物について「効率化基準 55」への適合義務が課せられた。従来は、必要な一次エネルギー需要を参照建築物水準の 75%に抑えることが義務付けられていたところ、当該改正で基準を 55%に引き上げた。さらに 2025 年からは新築建築物の基準が「効率化基準 40」に強化されるとともに、2024 年からは既存の建物の大規模な改築や増築の改修部分は「効率化基準 70」に適合することが求められる。

再生可能エネルギー利用についても、2021 年に再生可能エネルギー法を改正し、2024 年

から新たに設置される暖房設備の 65%以上を再生可能エネルギーで稼働することが求められた。当該義務と合わせて、2026 年初頭からは、暖房用オイルや固形化石燃料を燃料とするボイラーは、再生可能エネルギーによる代替手段がないなど一定の条件を満たした場合にのみ稼働させることができることとなる。純粋な化石天然ガス・石油ボイラーの最長運転期間は、2026 年から 30 年間から 20 年間に短縮される。

さらに、2022 年 4 月に閣議決定された EEG や洋上風力エネルギー法などの改正法案をパッケージとした「イースターパッケージ」に基づき、同年 7 月に再生可能エネルギー法が改正された。当該改正により、2030 年の総電力消費量に占める自然エネルギーの割合を 80%に高めることとした（2021 年時点で約 42%）。



出所：Hans Erhorn, Head of Department of Energy Efficiency and Indoor Climate, Fraunhofer IBP

図 2.1-1　一次エネルギー規制の変遷

財政支援の面では、建物のエネルギー効率化と再生可能な熱の利用のための財政的インセンティブとソフトローンのための資金が 2005 年から提供されているが、当該プログラムは 2021 年 7 月 1 日に大改正され、現在は「効率的な建物のための連邦資金（BEG)」という名称に変更、政府支出額も大幅に増大している（従来：約 20 億ユーロ/年→2021-22 年：約 50 億ユーロ/年）。今後も政府支出額は拡大予定で、2021/22 年の約 50 億ユーロ/年から、2026 年まで 120 億～140 億ユーロ/年となる見込みである。支出対象にも強弱を付け、エネルギー効率の非常に高い新築建物への助成額は削減される一方、既存建物のエネルギー効率改修に手厚く支給される。例えばエネルギー効率の最も悪い分類の建物の改修にあたっては、最悪クラスのエネルギー性能証明書を以て、WPB ボーナス（Worst-Performing-Building-Bonus)）が適用され、改修費用の 10%が補助金として支給される予定。

地域熱供給を行う自治体に対しても 2022 年 11 月 1 日より補助金が支給されることなった。補助金は対象経費の 90%に相当し、財政的に脆弱な自治体や褐炭地域の申請者には、100%の補助金が支払われる。

一方、日本においては、1970 年代の二度の石油危機を契機に、エネルギーの効率的な利用を促進すべく、1979 年に省エネ法が制定された。同法は制定当初はエネルギー多消費分野である工業部門や運輸部門の省エネを促進することに力点が置かれていたが、その後気候変動への意識の高まりや増大するエネルギー消費量に対処するため、家庭部門や業務部門も対象に含まれた。

1997 年に京都議定書が採択されると、日本は温室効果ガス削減目標を達成するため、主に民生・運輸部門の省エネ施策として、1998 年にトップランナー制度が導入された。当該制度は、基準値を策定した時点において、最も高い効率の機器等の値を超えることを目標とした最高基準値方式になっており、

制度導入当初は乗用車やエアコン等 11 品目から開始したが、その後対象品目を増やし、現在 32 品目が対象となっている。建材分野に関しては、建材トップランナー制度の枠組みの下、住宅の熱の出入りの 6、7 割が「壁、天井、床、開口部」となっていることから、断熱材（繊維系、発泡プラスチック系）、窓（サッシ、複層ガラス）を 2012 年より同制度の対象とし、2022 年度の目標達成を目指している。

表 2.1-2　トップランナー制度対象品目

トップランナー制度対象品目

特定エネルギー消費機器等を中心に32品目を対象としています。

乗用自転車	VTR	自動販売機	プリンター
エアコン	電気冷蔵庫	変圧器	電気温水機器（ヒートポンプ式給湯器）
照明器具	電気冷凍庫	ジャー炊飯器	交流電動機
テレビ	ストーブ	電子レンジ	電球
複写機	ガス調理機器	DVDレコーダー	ショーケース
電子計算機	ガス温水機器	ルーティング機器	断熱材
磁気ディスク装置	石油温水機器	スイッチング機器	サッシ
貨物自動車	電気便座	複合機	複層ガラス

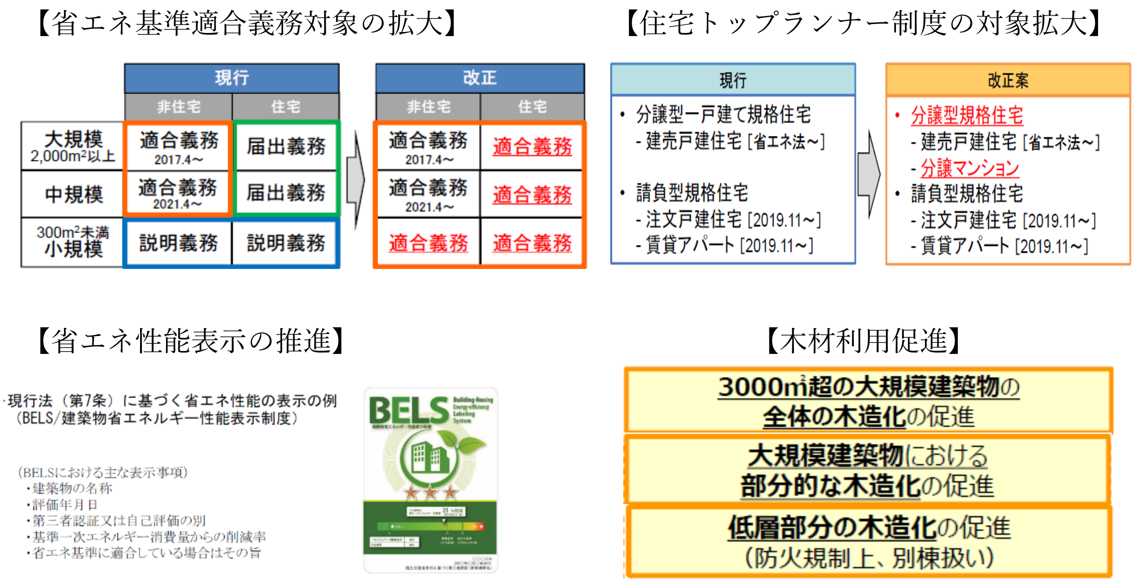
出典：資源エネルギー庁、https://www.enecho.meti.go.jp/category/saving_and_new/saving/assets/pdf/enterprise/enex2020/shiryo1.pdf

著しくエネルギー消費量が増加している建築部門への抜本的な省エネルギー対策強化を目的として、2015 年に建築物省エネ法が制定された。同法の特徴の一つとして、従来その適合が努力義務に留まっていた省エネ基準を、延床面積 2,000 ㎡以上の非住宅の新築・増築を行う建築主に対して適合義務が課した。また、誘導措置として、省エネ性能向上のための設備を設置したことで通常の建築物の床面積を超える場合、この部分を不算入するという、性能向上計画認定・容積率特例や省エネ基準適合表示制度が導入した。2009 年より省エネ

法の下で始まった住宅トップランナー制度も省エネ法から引き継ぎ同法管轄の下で対象範囲を広げていくこととなった。

2020 年、2021 年に発表された『2050 年カーボンニュートラル宣言』及び『2030 年 46%削減』を受けて、2021 年に国交省、経産省、環境省合同で住宅・建築物での省エネ対策のロードマップが纏められた。当該ロードマップにて、2030 年迄に新築建築物の ZEB/ZEH 化、2050 年迄にストック平均での ZEB/ZEH 水準の省エネ性能を確保するとの目標が示された。また、取組みの進め方として、家庭・業務部門では省エネの底上げや、機器・建材トップランナー制度の強化、省エネ性能表示の取り組み強化など（新築物件の広告での表示義務化）が掲げられ、再エネ導入拡大や、吸収源対策としての木材利用拡大も重要な施策として取り上げられた。

このロードマップに基づいて、2022 年 6 月に建築物省エネ法や建築基準法を含む関連法の改正が行われ、省エネ基準適合義務の対象拡大や住宅トップランナー制度の対象拡大のほか、自治体が主体となった再生可能エネルギーの普及、省エネ性能表示の推進（努力義務不履行への措置設定）、木材の利用促進のための各種規制緩和や住宅の省エネ改修への低利融資制度も創設されている。



出所：国土交通省、https://www.mlit.go.jp/jutakukentiku/build/content/001572929.pdf

図 2.1-2　関連法の主な改正内容

2.1.4　比較

日独で違いが顕著なのは、エネルギーの用途である。これは両国の地理上の位置に起因している。日本をヨーロッパと同経緯度に重ね合わせると、北海道はイタリア北部に位置するが、それ以外は地中海以南、九州に至っては北アフリカと同緯度になる。その為暖房度日は

ドイツで 3,500 - 4,000 日なのに対し、東京は 1,000 日程度である。人口の 70%を占める関東、関西、中部はいずれも温暖な地域であることから、日本の住宅は夏を旨とする構造となっており、そのため暖房はほとんどの家は部分間欠暖房となっている。北海道以外ではドイツのようにセントラルヒーティングを導入している家はほとんどない。

出所：Italia Zanmai, 2016-7-26, https://italiazanmai.com/press/260716/

図 2.1-3　日本と欧州の緯度

また、省エネ方法でも違いがある。ドイツでは暖房での省エネが最優先事項であるのに対し、日本ではエアコンを含む家電や照明、給湯機に対するトップランナー制度を充実させることに優先度が高い。

再エネ利用に関してもスタンスが異なる。両国ともに、より強固な外皮と効率的な暖房、換気、および空調を備えた新築建築を誘導する政策を持ち、再エネの普及にも積極的ではある。ドイツは 2021 年に再生可能エネルギー促進法を改正し、2024 年以降の新築建築物へは 2030 年までに電力消費量に占める再生可能エネルギーの割合を 65%とすることを義務づけた。

一方、日本は、国が全国一律の規制措置を設けるよりも、地域の実情をよく知る市町村にその促進を託すこととし、市町村が、再生可能エネルギー利用促進区域の指定や設置を促す再エネの種類等を含めた促進計画を作成することとしている。従い、ドイツのように政府が再エネ導入を義務するまでには至っていない。

省エネ改修についても、ドイツでは多彩な補助金拠出と専門的アドバイスをもって推進

し、かつ改修済み物件のマーケットでの評価も高いことから、10 年以内で改修費用を回収できるとの調査結果も出ている。

一方、日本は改修を検討する場合、便利さ・快適さ、バリアフリーを優先する傾向にあり、10‐15 年でエアコンやボイラーは交換するが、二重窓の設置や壁の高性能断熱工事にはあまり前向きではない。その理由の一つが、省エネ投資の回収に時間を要するということと、そもそも省エネ改修への必要性を感じていないことにある。これらのハードルは住宅の改修に限ったことではなく、非住宅でも起こっており、改修工事よりも、高性能な設備や機器への入れ替えに意識が向く。また、効果的な改修工事には適切な検査と計画、それらは追加費用が伴うが、それらを支える仕組みが日本では不十分であることも、省エネ改修が進まない一因であろう。

政策面での違いも興味深い。省エネ対策には両国とも長い歴史を有する。ドイツは 1977 年、日本は 1979 年に省エネ関連法を制定した。ドイツで、主に建物の外皮と暖房システムのエネルギー効率に対する規範的な価値を設けたのに対し、日本は 1998 年に導入されたトップランナー制度で、家電のパフォーマンス向上に焦点をあてた。この省エネのアプローチの違いには、前述の通り地理的環境や気候、住文化の違いに起因している。

2.1.4　提言

今回の調査を通じて、ドイツにとっては、家電等の省エネ性能を図るトップランナー制度の優れた点を EU 主導の Ecodesign 制度に取り入れることや、木材利用に促進にあたっては、防火対策の点で日本の施策から学ぶ点が多い。日本は既存建築物へのエネルギー効率向上に向けた取り組み（断熱や熱回収換気システム、再生可能エネルギー設備設置強化）の実効性を担保する施策が、ドイツ側から優先して学ぶべき点といえよう。

一方で課題も認識することができた。両国に共通するところでは、省エネ政策を進めるにあたっての実行可能な目標の明示である。具体的には省エネ改修や石油・ガス等の化石燃料由来の暖房の段階的廃止、ヒートポンプの具体的な導入数と目標年など、明確な目標設定が不足している。建築物の延床面積拡大に歯止めをかけることも、エネルギー消費量削減と Embodied carbon[1]の排出抑制に効果的である。また、さらなる改修を誘導するために、財政支援の強化や進捗モニタリングの徹底、「Building Renovation Passport」のような建築物の改修状況を表示する制度や「One stop shop」のような一括サポート体制を構築することが、改修促進に資すると考えられる。

日本については、まず既存建築物への対策が急務である。前述の通り既存建築物の多くが耐震性を備えておらずかつ省エネ基準を満たしていない。また改修工事を行うにあたって

[1] 内包二酸化炭素。建材の製造や運搬、建築などの段階で排出する CO2 のこと。これに対して、建物を利用する段階で家電などが排出する CO2 は Operational Carbon と呼ぶ。

も、どのような工事が必要かを適切に評価する体制が不十分であることや改修工事を熟知した熟練作業員が不足していることも、省エネ改修が進展していない理由と考えられる。今後はさらには、改善された断熱材や日照遮蔽による健康メリットを周知させることも、省エネ改修の多様なメリットの認識に寄与する。建築物への再生可能エネルギーの導入加速も、市町村と政府がしっかり連携を取って進めていくことが求められる。

2.2 エネルギー多消費産業の脱炭素化 – （石油）化学産業 -

2.2.1 （石油）化学産業の特徴

ドイツも日本も化学産業は非常に大きな産業と位置付けられており、両国の経済や雇用を下支えしている。石油精製の副生成物であるナフサを起点に、エチレンやプロピレンなどの基礎化学品から、プラスチックや合成ゴム、合成繊維、塗料、溶剤、界面活性剤、電子材料、医薬品原料などあらゆる化学製品を幅広く生産している。そして世界の化学産業の中でもドイツと日本は 5 本の指に入る輸出大国である。

それと同時に、両国の化学産業は、気候変動への影響に対しても大きな責任を負っている。すなわち、様々な部門の中でも大きな CO_2 排出源のひとつになっている。ドイツでは化学産業部門からの CO_2 排出量は約 3,890 万トンにのぼり、ドイツ全体の CO_2 排出量の約 5.3%を占めている（2020 年）。日本の化学産業部門からの CO_2 排出量は約 5,600 万トンを記録しており、産業部門の約 15%、日本全体の CO_2 排出量の約 5.6%を占める（2019 年度）。両国とも全 CO_2 排出量の約 5%を化学産業からの CO_2 排出量が占めており、両国の産業構造に大きな共通点があることが分かる。

一方、またドイツは 2045 年までに、日本は 2050 年までにそれぞれカーボンニュートラルな社会の実現を目指しており、その目標を達成するためには、化学産業からの CO_2 排出から目を逸らすことはできない。そして、将来、大幅に CO_2 を削減するためには、化学産業を含めた社会全体のエネルギーシステムを大きく変革させる必要がある。

ドイツの化学産業はライン川流域を発祥とし、石炭資源や他の産業立地、港や陸上輸送、エネルギーや資源のパイプラインへの接続が良好な場所などを総合的に判断され、産業クラスターが形成されている（図 2.2-1 左）。現在はドイツ国内には 6 つの産業クラスターがある。西はライン川沿いのエムシャー＝リッペ、ラインランド、ルートヴィヒスハーフェン、北は海沿いのノルトゼー、東は中央ドイツ化学ネットワーク、南はバイエルンの 6 つである。そのほか、ベルギーのアントワープやオランダのロッテルダムなど、海外都市と石油パイプラインで統合されるようなクラスターもある。産業クラスターは、特に天然ガスのインフラで強く接続され、エネルギーを天然ガスに依存している。6 つのクラスターのうち 4 つは、一次エネルギー供給量の 40～70%が天然ガスで占められている。天然ガスとの接続が無いクラスターでは製油所がある。2045 年までにカーボンニュートラルを目指すという目標に対しては、ケミカルリサイクルやバイオベースの原料代替品の導入を試みているが規模は未だ小さい。

一方、日本は海に囲まれた島国であり、自国のエネルギー資源も豊富ではない。かつては石炭も採掘していたが、今は稼働していない。天然ガスや石油の埋蔵量も多くは確認されていない。現在はエネルギー資源のほとんどを海外から輸入しており、日本のエネルギー自給率は約12%である。日本の化学産業が沿岸部や港湾周辺に集中しているのは、エネルギー資源を輸入に頼っていることが原因である（図2.2-1右）。将来、脱炭素社会の実現に有望な水素やアンモニアなどの燃料を導入することを想定した場合、そのほとんどを海外からの輸入に頼らざるを得ないため、臨海部の立地が非常に重要である。日本ではこうしたCO_2フリー燃料（資源）を安定的かつ安価に大量に輸入する機能を整備し、将来的に温室効果ガスを大幅に削減するカーボンニュートラルポート（CNP）の形成に向けた検討が行われている。

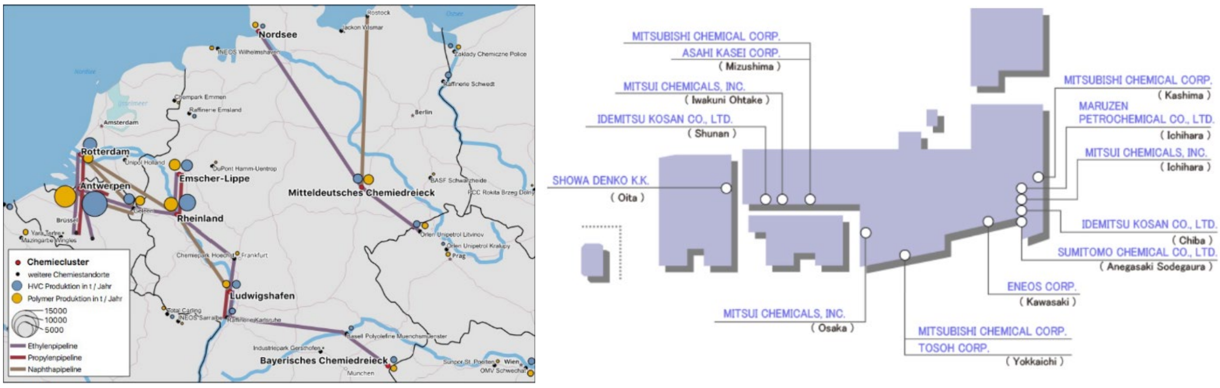


図2.2-1　ドイツ（左）および日本（右）における化学産業の分布図

出所：日独エネルギー変革協議会第2回資料，2023.3

化学産業のエネルギー源は、石油、石炭、天然ガスなどの化石燃料（資源）と電力である。日本の場合を例に取ると、石油化学分野で消費されているエネルギーは約747PJであり、その内訳は、石油約45%、石炭約17%、天然ガス約11%、電力約26%である。つまり、例え石油化学部門の消費電力のすべてを再生可能エネルギーで供給しても全体の約26%（約191PJ）しかゼロエミッションにならない。残りのエネルギーは化石燃料（資源）によるものであり、ここに対して何らかの対策を講じなければ、抜本的なCO_2削減は望めない。つまり、石油・石炭・天然ガスの消費量に相当するエネルギーを、CO_2フリーの原料・燃料に置き換える必要がある。

2.2.2　（石油）化学産業における脱炭素へのシナリオ（ロードマップ）

日独のシナリオ（ロードマップ）

ドイツでは2045年までにカーボンニュートラルを目指す国の目標に対し、政府機関や産業連盟（BDI）からエネルギーシステムに関するシナリオ分析が実施されている。表1にドイツのシナリオ（ロードマップ）の事例を示す。

表 2.2-1　ドイツのシナリオ（ロードマップ）

	Code	Title	Made by	Commissioner	Year
①	**RoadChem**	Roadmap Chemie 2050 Auf dem Weg zu einer treibhausgasneutralen chemischen Industrie in Deutschland	Dechema and FutureCamp	VCI	2019
②	**Wege**	Wege in eine ressourcenschonende Treibhausgasneutralität	UBA	-	2019
③	**DenaLeit**	dena-Leitstudie – Aufbruch Klimaneutralität	EWI	dena	2021
④	**KlimaPfade**	KLIMAPFADE 2.0 Ein Wirtschaftsprogramm für Klima und Zukunft	BCG	BDI	2021
⑤	**Langfrist**	Langfristszenarien für die Transformation des Energiesystems in Deutschland 3	Consentec, Fraunhofer ISI, ifeu, TU Berlin	BMWi	2021
⑥	**DeAufWeg**	Deutschland auf dem Weg zur Klimaneutralität 2045 Szenarien und Pfade im Modellvergleich	Kopernikus-Projekt Ariadne and Potsdam-Institut für Klimafolgenforschung (PIK)	BMBF	2021

出所：日独エネルギー変革協議会第 2 回資料，2023.3

①は化学部門に特化した内容となっており、2045 年において、2020 年比で 61%および 97%の排出削減を達成する 2 つのシナリオが示されている。

②はドイツ連邦環境庁（UBA）によるもので、他で取り上げられている部門とは別に、廃棄物・廃水部門、農業・土地利用についての章を設けている。温室効果ガスの排出量、原材料の消費量、地球規模での影響について論じている。分析は 6 つのシナリオがあり、2050 年までに 1990 年比で 95%以上排出を削減するドイツを描いている。

③は建築、産業、交通、エネルギーの各分野に対して詳細なシナリオを分析しており、化学産業についてもモデル化されている。また市場設計、イノベーション、社会的な定着、国際的な相互作用などにも言及している。

④は産業連盟 BDI のシナリオ分析であるが、②のシナリオに良く似ている。産業、運輸、エネルギー、建物についてシナリオ分析し、化学産業は産業の一部としてモデル化されているほか、投資やコスト、政策課題について言及し、政策提言している。

⑤は 1 つのエネルギー源（電気、水素、PtG/PtL）に依存する 3 つの将来シナリオを調査・分析したもので、産業部門は、基礎化学、鉄鋼、セメント・石灰部門がモデル化されている。

⑥は産業、運輸、建築、エネルギーの分野に対し分析しているが、水素や e-fuels の役割、セクター間の相互作用、セクター連携などについても分析し、政策提言まで記載されている。2045 年までのエネルギーシステムを実現するために、電力や水素の輸出入、電熱

変換などをミックスした6つのシナリオがモデル化されている。化学産業についても言及されているが、定量的な分析はなく、そのモデル分析は④と同じものである。

①～⑥以外にも、ドイツを代表するBASF、Dow、Sabic、Ineos、LyondellBasell Industries、DuPont、Covestroなどの企業が2050年までにネットゼロエミッションを達成する目標を掲げ、様々なシナリオを描いている。

一方、日本では、2030年までに2013年度比で温室効果ガス排出量を46%削減し、2050年までにカーボンニュートラルを目指すとしており、代表的なシナリオ（ロードマップ）としては以下（表 2）の5つがある。

表2.2-2　日本のシナリオ（ロードマップ）

	Title	Made by	Year
1.	Energy Saving Technology Strategy	METI and NEDO	2019
2.	The Sixth Basic Energy Plan and Long-Term Energy Supply and Demand Outlook	METI	2021
3.	Roadmap for Carbon Recycling Technologies	METI	2021
4.	Green Growth Strategies Associated with 2050 Carbon Neutrality	METI	2021
5.	Keidanren Carbon Neutrality Action Plan -- Vision toward Carbon Neutrality by 2050 and Fiscal 2021 Follow-up Results (Performance in Fiscal 2020) --	KEIDANREN (Japan Business Federation)	2022

METI: Ministry of Economy, Trade and Industry, Japan
NEDO: New Energy and Industrial Technology Development Organization, Japan

出所：日独エネルギー変革協議会第2回資料，2023.3

①は経済産業省（METI）が2007年より発表しているもので、政府のエネルギー基本計画などの方針を反映させながら、化石資源（燃料）の消費量削減とCO_2排出量の削減を目指した戦略である。2019年の改定では、廃熱や再生可能エネルギーを主電源として活用するための省エネルギー技術が重点技術に挙げられている。具体的には、廃熱の有効利用や熱エネルギーの循環利用、高効率電気加熱技術（誘電加熱、レーザー加熱、ヒートポンプ加熱）などが挙げられている。現在、2021年に発表された「第6次エネルギー基本計画」に基づき、省エネルギー戦略の見直しが検討されている。

②は政府のエネルギー政策の基本的な方向性を示すもので、安全（Safety）を前提に、エネルギーを安定的に供給でき（Energy Security）、低コスト（Economic Efficiency）、環境適合性（Environment）を目指したシステム（S+3E）に基づいて公表されている。焦点は、「2050年のカーボンニュートラル化」を実現するために、2030年までにGHG排出量を2013年比で46%削減することにある。長期エネルギー需給見通しによると、一次エネルギ

ー供給量に対し、石油 31%、再生可能エネルギー22〜23%、石炭 19%、天然ガス 18%、原子力 9〜10%、水素・アンモニア 1%となっている。

③は、CO_2 を炭素資源として扱い、化学材料や燃料の生産、鉱石化原料などに活用し、CO_2 排出を抑制できるとするカーボンリサイクルの戦略とロードマップを示したものである。ロードマップでは、(1) 早期展開を目指すもの（水素を必要としないものや付加価値の高いもの）は「2030 年頃」、(2) 中長期展開を目指すもの（汎用的なもの）は「2040 年頃」としている。

④は 2050 年のカーボンニュートラル実現に向けた技術戦略である。今後、成長が見込まれる 14 の分野を選定し、手厚い予算配分を行うとしている。化学産業に特化した分野は選定されていないが、原料、電力、熱（蒸気）に関する技術開発が選定されている。14 分野とは、(1) 再生可能エネルギー、(2) 水素・アンモニア、(3) 熱利用、(4) 原子力、(5) 自動車・蓄電池、(6) 半導体・情報通信、(7) 船舶、(8) 物流・人流・インフラ、(9) 食料・農林水産、(10) 航空機、(11) 炭素循環・素材、(12) 住宅・建設・電力マネジメント、(13) 資源循環、(14) 生活分野である。

⑤は日本経済団体連合会（以下、経団連）が国内産業界のカーボンニュートラル実現に向けた行動計画をまとめたもので、毎年公表している。経団連は各産業界に BAT（Best Available Technologies）の最大限の導入により、CO_2 排出量を効果的に削減する努力を呼びかけており、各業界の進捗状況を調査し、方向性を検討・修正している。石油化学（化学産業）部門のカーボンニュートラル行動計画は、日本化学工業協会（日化協）が取りまとめ、経団連に提出している。日化協によると、化学産業は、2030 年までに 2013 年度比で 2,000 万トンの CO_2 排出量削減を目指すとしている。また、2050 年に向けては、CO_2 からプラスチックを製造する技術や人工光合成、バイオマスの積極利用などが記載されている。さらに日化協は独自の LCA 評価指標「cLCA（カーボンライフサイクル分析）」を提唱し、原料の採取、製造、流通、使用（消費）、廃棄の各プロセスで排出される CO_2 量を試算する手法を提示している。そのほか、石油連盟が「石油産業のカーボンニュートラルに向けたビジョン（目指すもの）」を発表し、2050 年に向けて、廃食油や廃プラスチックのリサイクルの推進、バイオマス原料の活用、サステイナブル航空燃料（SAF）の製造、CO_2 フリー水素の製造・利用による合成燃料の製造など、革新技術の開発について言及している。

原料に対する考え方

化学産業における CO_2 排出源は原料、電力、熱（蒸気）の 3 つに大別されるが、ここでは原料に対する CO_2 排出削減に向けた考え方をドイツと日本とに分けてまとめる。

ドイツのシナリオ（ロードマップ）では、リサイクル原料、バイオマス原料、CO_2 回収による原料など、原料の脱化石資源（燃料）化に関する全てのオプションが採用されている。シナリオの中には、化石原料が残るもの（化石原料を使用せざるを得ないシナリオ）もある。将来は、シナリオにもよるが、カーボンニュートラルを目指すためには CO_2 ベースの代替

原料がシェアの半分以上を占める。ただし水素を添加する必要があり、水の電気分解によって水素を製造するためには、大量の再生可能エネルギーが必要になる。水電解によるグリーン水素製造が最も一般的とされるが、メタン熱分解や炭素回収（CCS）を伴う化石燃料からの水素製造（ブルー水素）もオプションとして加えられている。さらに CO_2 と水素からメタノールを製造し、MTO または MTA ルートでさまざまな化学物質を製造する方法や、H_2 の添加により合成ガスを製造して合成ナフサを製造し、さらにフィッシャー・トロプシュ法（FT 法）でさまざまな炭化水素を生産する方法がある。この方法なら既存のナフサプラントやインフラをそのまま使用することができる。

日本の石油化学分野では、石炭と石油が原料として使用されている。その量は、石炭が 129 PJ（約 17%）、石油が 341 PJ（約 45%）である。これらの原料を CO_2 フリーにするには、バイオマス由来の原料に変えるか、CO_2 から石油製品の原料を製造するしかない。日本ではこれまで、バイオマスを化学産業の原料（バイオナフサ）として利用する試みはほとんどない。日本では CO_2 から製品を製造する研究開発が活発に行われており、例えば、CO_2 からオレフィンなどを生産する国家プロジェクトが進行中である。加えて、廃棄物や廃食油、廃プラスチックの再利用は非常に重要であり、日本におけるプラスチックの回収率は約 87%（2021 年）と高い。回収したプラスチックの処理方法の内訳は、リサイクル（マテリアルリサイクル＋ケミカルリサイクル）25%、サーマルリサイクル 62%、その他（焼却＋埋め立て）13%となっている [2]。一方欧州では、回収したプラスチックの処理方法の内訳は（2020 年）、リサイクル 35%、サーマルリサイクル 42%、埋め立て 23%となっている [3]。日本の方が有効利用率は高く、処理方法別には、日本はサーマルリサイクルが多い。

電力に対する考え方

ドイツのシナリオでは、化学産業は将来電化が進むと予想されている。その電力はそのほとんどを陸上・洋上風力発電と太陽光発電によって生産され、プロセスは、ヒートポンプ、電熱ボイラー、電気加熱炉が導入される。場合によってはスチームクラッカーへの電熱利用も利用される。さらにバイオマスやバイオガスによる電力もしくは燃料供給によっても補填される。燃料は使用する温度帯によって振り分けられ、例えばバイオガス、水素、合成燃料は高温で使用し、低温度帯に対しては地域暖房も大きな役割を果たしながらボイラーによって柔軟に燃料を調節・対応して運用するとされる。

日本の電力構成は、石炭 31%、石油 6.4%、天然ガス 39%、水力 7.8%、再生可能エネルギー12%（2020 年度）である。そして日本は発電用燃料のほとんどを海外からの輸入に頼っている。将来、電力の脱炭素化には、ドイツと同様に再生可能エネルギーの活用が

[2] 一般社団法人プラスチック循環利用協会, 2021 年プラスチック製品の生産・廃棄・再資源化・処理処分の状況, 2022.12

[3] Plastics Europe, Plastics – The Facts 2022, 2022.10　欧州＝EU27 か国＋ノルウェー、スイス、イギリス

欠かせないが、日本の石油化学産業の電力消費量約 191PJ を全て再生可能エネルギーで代替するなら、太陽光発電で 4,300 万 kW、風力発電で 3,000 万 kW（それぞれ太陽光発電設備利用率 14%、風力発電設備利用率 20%として換算）が必要である。現在、日本の再生可能エネルギーの中で最も導入が進んでいる太陽光発電の設備導入量は、約 6,500 万 kW（2020 年度）である。つまり、石油化学業界が消費する全ての電力を太陽光発電でまかなうとすると、既存の太陽光発電設備の約 2/3 を化学産業で使用しなければならない。そもそも日本は日射量や風況の良い土地が限られており、再生可能エネルギーの送配電ネットワークが整備されていないため、系統の強化や出力安定のための技術開発などが実施されている。

一方、再生可能エネルギー以外による CO_2 フリー電力供給も検討されている。固形燃料では、主にバイオマスや廃プラスチックなどの利用、液体燃料では、水素キャリア（アンモニア、MCH（メチルシクロヘキサン））や CCU 製品としてのメタノールやエタノールの利用、そして気体燃料では、水素や合成メタン、バイオガスなどである。メタノールやエタノールは燃焼すると再び CO_2 が発生するので、回収した CO_2 を原料として使うことや、燃やした後の CO_2 を回収するなどカーボンリサイクルを考える必要がある。大気中から回収した CO_2 を利用すること（DAC）や CCS も重要である。

熱（蒸気）に対する考え方

熱の脱炭素化には、(1) 未利用熱（廃熱）の有効利用、(2) CO_2 フリー熱源、(3) 電熱変換の利用、の 3 つの方法がある。

(1)廃熱は、ほとんどの技術プロセスで副産物として発生するにもかかわらず、利用されずに失われることが多い。廃熱の利用には、蓄熱技術、ヒートポンプ、吸収・吸着式冷凍機、熱電発電機などが重要な役割を担っている。廃熱利用には廃熱源と消費者の熱需要とのバランスが非常に重要である。温度帯、熱量、廃熱の流れ、熱供給と熱需要のタイミング、熱媒体の種類、地域条件などを精査する必要がある。未利用の熱（廃熱）を有効利用することは、化石燃料の消費を削減できるが、化石燃料を熱源として使用する限り、CO_2 排出量をゼロにすることはできない。この燃料を CCU 燃料に置き換えることで、熱源の CO_2 フリー化が実現できる。

(2)CCU 燃料を使用する場合、DAC により CO_2 で製造する場合を除き、燃焼（蒸気製造）後に排出される CO_2 を回収するカーボンリサイクルが重要となる。日本では、ガス業界を中心に CO_2 と水素から合成する合成メタン（e-メタン）の開発が盛んである。

(3)電熱変換技術による熱の電化については、ドイツが注目する技術である。電力の項で記載したように、ドイツでは将来は電化、すなわち電熱変換が中心になると予測している。ただしその電力供給源とその規模についての詳細な言及はない。日本での熱電変換は省エネルギー技術戦略（2.1 章の日本の①の戦略）で技術列記されているものの、大きな市場はない。これを大規模化する場合は、再生可能エネルギーによる大規模な電力確保など、大き

な課題が残る。

時間軸に対する考え方

将来の GHG 排出量削減のための目標達成のためには、技術やインフラが整備されるのはいつで、どのような投資がどのタイミングで実施されるのか、そして、いつのタイミングで新技術が CO_2 排出量削減とネットゼロに貢献するのか、が一番の関心事である。ロードマップには目標年の導入目安は示されているが、それまでの具体的な工程は分からない。

ドイツでは新技術が利用可能になるのは 2030～2035 年頃とし、2040 年には一般に利用されると考えている。例えばメタノールからオレフィンを製造する MTO 技術については、回収した CO_2 からのメタノール製造を含めて KlimaPfade（2.1 章のドイツ戦略の④）では 2025 年までに、KlimaDe（2.1 章のドイツ戦略の⑥）では 2040 年までに、それぞれ利用可能になるとしている。この技術の市場導入後、10 年から 15 年の間に急速なスケールアップが行われ、いくつかのシナリオでは、2035 年以降に CO_2 排出量は急速に減少するようにモデル化されている。一方で直線的に減少すると予測するシナリオもある（図 2.2-2）。

日本でも時間軸に対する技術開発の工程はよく議論される。2050 年までの限られた時間の中で、カーボンニュートラルな社会を確実に実現するためには、既存の技術やインフラを有効に活用すると同時に、革新的な技術開発を同時並行する必要がある。経済産業省が発表したカーボンリサイクル技術ロードマップ（2.1 章の日本の戦略③）では、研究開発を 3 つのフェーズに分けて行うことが示されている（図 2.2-3）。CO_2 から様々な製品を製造することができるが、既存の技術やインフラを有効活用できる製品は、技術実証を通じてフェーズ 1（～2030 年）で製造し、フェーズ 2（2030 年前後）で実用化する。例えば、水素を必要としない鉱物（コンクリートなど）や、すでに実用化されているバイオジェット燃料、ポリカーボネートなどは、フェーズ 1 で開発される製品である。 消費量の大幅な拡大が見込まれるフェーズ 3（2040 年～）は、開発・普及に時間がかかる合成燃料や化学物質がいよいよ実用化される。しかし、カーボンリサイクルで作られた原料や燃料、電力などの市場導入規模や必要なコスト（費用対効果）、CO_2 削減効果などについては、これまで具体的に議論されていない。これは、企業の経営判断にも関わることであり、大きな問題である。

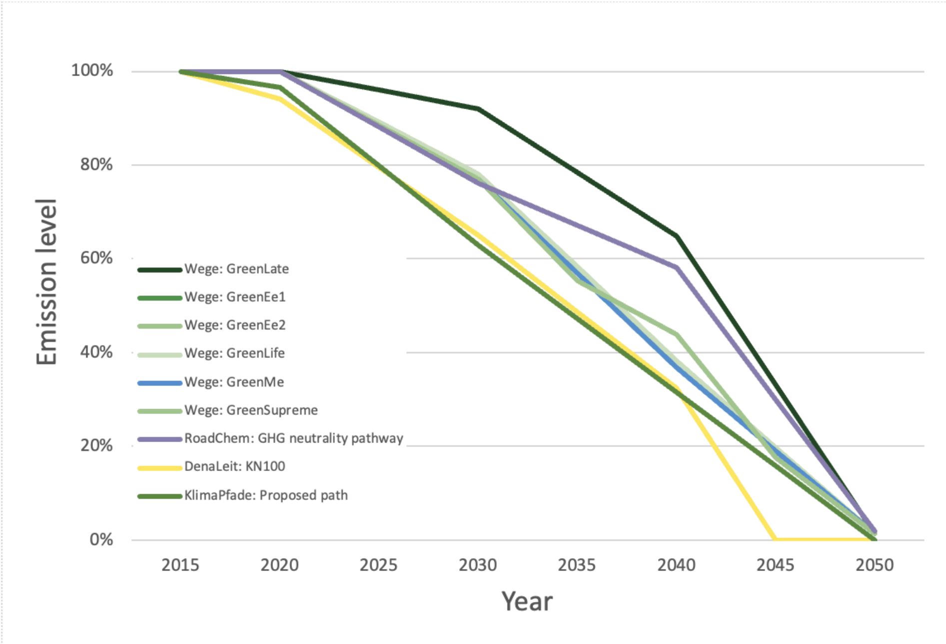


図 2.2-2　ドイツの CO_2 削減パス

出所：日独エネルギー変革協議会第 2 回資料，2023. 3

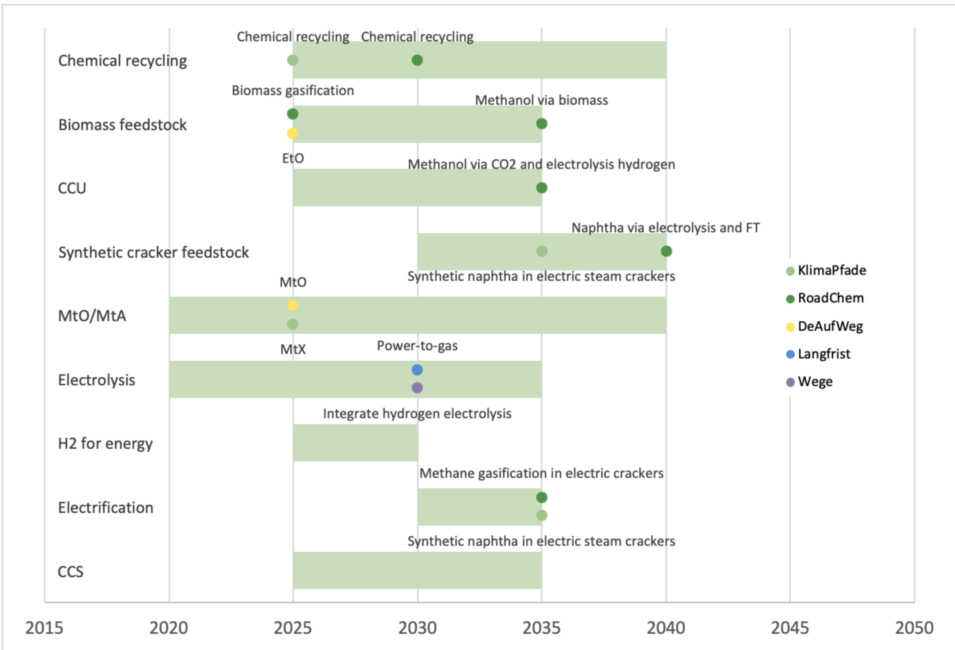


図 2.2-3　ドイツの技術開発ロードマップ

出所：日独エネルギー変革協議会第 2 回資料，2023. 3

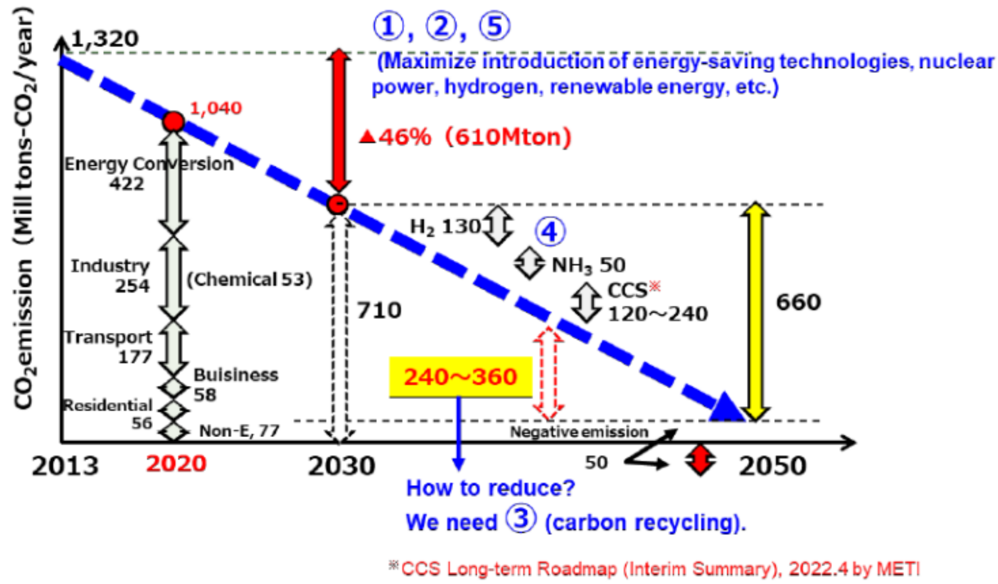


図 2.2-4　日本の CO_2 削減パス

出所：日独エネルギー変革協議会第 2 回資料，2023. 3

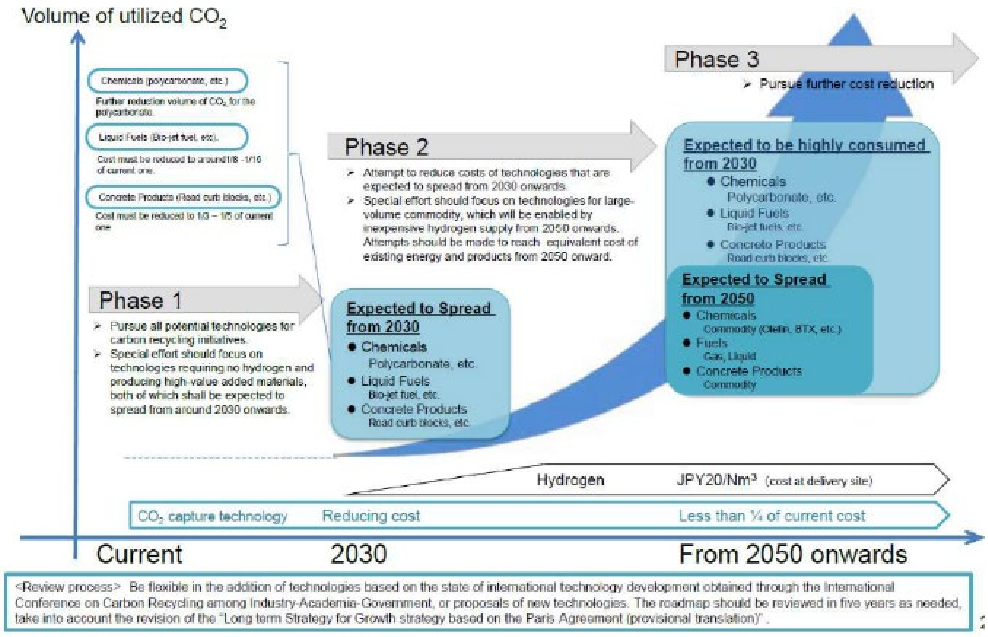


図 2.2-5　日本のカーボンリサイクル技術ロードマップ

出所：日独エネルギー変革協議会第 2 回資料，2023. 3

シナリオ（ロードマップ）の課題と展望

化石資源（燃料）に完全に依存している化学産業のエネルギーシステムの転換には、インフラ整備も含めて多額の投資経費がかかる。何十年もインフラや設備を使用し続けること

を前提としたシステムに必要な投資を行うには、ビジネスケースが明確で不確実性が少ないものでなければならない。こうした化学産業のビジョンが明確化されないと、低炭素であろうとなかろうと、経済的に優遇されている海外に企業が移転してしまうリスクがある。このリスクの要因となっているのは、天然ガスと電力の価格構造、再生可能エネルギーによる電力の規模や安定性・信頼性、さらに水素や CO_2 廃棄物に対するインフラの整備などが挙げられる。

日本でも CO_2 フリーの原料、電気、熱（蒸気）に変換する技術はすでに存在し、カーボンニュートラルに向けてそれらを生産することは科学的に可能である。カーボンリサイクル技術ロードマップは、これらの技術をいつ、何を導入するかを時間軸に沿って定性的に示している。実現すれば、カーボンニュートラルに大きく近づくことになるが、それぞれの技術や CO_2 フリー製品を市場化した場合の CO_2 削減量や費用対効果について明確になっていない。そのため、企業は投資を躊躇する原因となっており、大きな課題である。

ここまで紹介してきた様々なシナリオ（ロードマップ）は、自然災害、新型コロナウイルス感染症の世界的な広がり、ロシアのウクライナ侵攻、米国のインフレ抑制法、中国の動向など、様々な社会的な要因によって大きく影響を受ける。

ドイツの化学産業はクラスターが形成されているが、その多くが天然ガスに大きく依存している。ドイツの化学産業業界におけるガス消費量は全体の約 15%を占める。そのためロシアによるウクライナ侵略の影響は大きい。ガス価格や電力価格の高騰は化学産業の設備閉鎖を引き起こし、特にガス集約型の肥料製造は、多くの設備が閉鎖した。欧州委員会は 2022 年 11 月にロシアのエネルギー依存度を下げる方策として、自然エネルギーの導入を加速させる計画を発表している。

日本はエネルギー自給率が非常に低く、これらの影響でサプライチェーンが寸断されれば、石油化学メーカーからの製品供給が途絶え、社会経済への影響が非常に大きくなる。化石資源（燃料）の地政学的な考察は、日本でも様々な場面で行われてきた。そのため、化石資源（燃料）の海外依存の是正や生産拠点の分散化について、日本では議論が続けられている。カーボンニュートラルな社会を実現するためには、再生可能エネルギー鍵であるが、日本の場合はその輸入（海外依存）も範疇に入れておく必要がある。

2.2.3　日独比較

ドイツと日本の化学産業における比較を表 2.2-3 に、そしてシナリオ（ロードマップ）に関する比較を表 2.2-4 に示す。

ドイツと日本には共通点が非常に多い。産業の規模はほぼ同じであり、今世紀半ばにカーボンニュートラル社会を実現するという目標も両国一致している。さらに、両国とも国内のエネルギー資源に乏しく、海外からの輸入に頼っている。そしてカーボンニュートラル社会を実現するための方法をともに探っているものの、残念ながら未だ解決策を見出せておらず、近年のエネルギー価格の高騰に対してどのように対処すべきか考えあぐねている。

ドイツと日本との決定的な違いは、その地理的な環境にある。ドイツは隣国と陸続きであるのに対し、日本は海に囲まれた島国である。このことは、安全保障を前提としたエネルギーの安定供給を達成するために必要不可欠となるインフラや、企業間のサプライチェーンの構築、さらには世界のエネルギーマーケットとの親和性に非常に大きな影響を及ぼす。特に日本の場合は、パイプラインによるエネルギー供給が現実的ではないため、船舶によるエネルギー輸送に頼らざるを得ない。つまり、万が一に備えるなら、エネルギー源の多様性を追求する必要がある。また、化学産業におけるエネルギー源にも違いがある。ドイツは主に天然ガスを利用しているのに対し、日本の場合は、天然ガス以外に石炭や石油も利用している。ドイツはロシアからの天然ガスが途絶しているため、天然ガスの価格が高騰し、化学産業が大きな影響を受けている。日本も影響を受けているが、エネルギーの多様化もあり、ドイツほどではない。

ドイツと日本のロードマップの違いも幾つか存在する。まず、ドイツは隣国と陸続きであるため、バリエーション豊かなエネルギー供給を図ることができる。一方の日本は海に囲まれた島国であるがゆえに、エネルギーの海上輸送に頼らざるを得ない。それゆえに、ドイツは電化に注目しているが、日本では CO_2 フリーなエネルギーを海外から船舶にて調達することを前提としている。そしてロードマップの理念として、ドイツは再生可能な資源の確保を目指しているのに対し、日本ではエネルギーの安全保障やエネルギー効率性を第一に考えている。

表 2.2-3　ドイツと日本の化学産業における類似点と相違点

Similarities and common challenges	Differences and specific challenges
Similarities • Similar size industries • Mid-century net-zero targets • Limited domestic resources – import dependent	**Differences** • Land connections to other countries 　• Different infrastructures affects value chains, dependencies, and closeness to world market • Energy mix to chemical industry 　• Gas in Germany 　• Coal and oil in Japan
Common challenges • Finding ways forward to reach net-zero targets • High energy prices	**Specific challenges** • Germany: Increased gas prices

出所：日独エネルギー変革協議会第 2 回資料，2023. 3

表 2.2 4　ドイツと日本のシナリオ（ロードマップ）における類似点と相違点

Similarities

- Mid-century net-zero targets
- Limited domestic renewable resources – import dependent
  - Importing synthetic fuels and feedstocks
- Focus on CO_2 recycling

Differences

- Roadmaps specificity for chemical industry
- Land connections to other countries
  - Germany: Varied supply
  - Japan: Only seaborne
- Non-feedstock energy use
  - Electricity in Germany
  - Range of imported fuels in Japan
- Framing
  - Renewable resource narratives in Germany
  - Energy security issues and efficiency in Japan

出所：日独エネルギー変革協議会第 2 回資料, 2023.3

2.2.4　まとめ

将来のカーボンニュートラル社会の実現に向けて、ドイツと日本はともに協力し、学び合い、そしてお互いの強みや弱みを理解し合った上で、お互いの国力を強化するための行動を起こす必要がある。お互いを知り、学び合うべきポイントは大別すると以下の 4 つである。

① それぞれの国が欲しているエネルギー資源の種類と、経済性や環境性を確保できる輸入要件は何か？

② 化石燃料や化石資源に替わる新しい原料や化学品は何か？

③ カーボンニュートラル社会を実現するために必要な新しい技術やシステムの開発を促進させること。

④ 将来のカーボンニュートラル社会実現のために政策決定された、例えば CO_2 排出量の削減目標に対して、現実と将来目標とのギャップを正確に理解しながら、目標にたどり着く間のトランジション期間にやるべきことを、透明性をもって提示すること。

こうした行動を起こす事と同時に、世界の市場や貿易協定の動向への注視を怠ってはならない。例えばメタノールやアンモニア、脱炭素に資する代替ナフサ（バイオナフサなど）などの世界市場は重要である。そして、再生可能な原料、水素を始めとするエネルギーキャリアの輸出入先候補へのアプローチなども不可欠である。

2.3 廃熱利用

2.3.1　廃熱利用の重要性

廃熱は、ほとんどすべての技術プロセスで副産物として発生するにもかかわらず、利用されることなく失われることが多い。熱エネルギーの大部分が無駄になるため、技術プロセスの全体的なエネルギー効率を低下させ、持続不可能なプロセスにつながる。したがって、廃

熱の利用を改善することは、エネルギー効率の向上につながり、同時にエネルギーコストも削減することができる。

2.3.2　廃熱のポテンシャルと利用

産業部門における代表的な廃熱源とその温度レベルを図 2.3-1 に示す。工業プロセスや各機器は、その運用・運転によって熱を発生させる。この熱エネルギーは、加熱された空気や排水の形で放出され、熱交換器によって回収されることで、別の熱プロセスに移すことが可能である。この技術は、ヒートポンプや換気装置にも利用されている。

工場や建物内での熱利用（内部利用）と工場外などの第三者での熱利用（外部利用）に関しての概要を表 2.3-1 に示す。内部利用では、保温断熱やプロセスの最適化、熱回収、電力への変換などが重要な検討要件となる。また内部利用できない熱は、近隣会社などへ移動し、外部利用することが可能である。廃熱を地域熱供給網や近隣企業に供給することで、気候変動に左右されない建築ストックや産業という目標の達成に大きく貢献することができる。

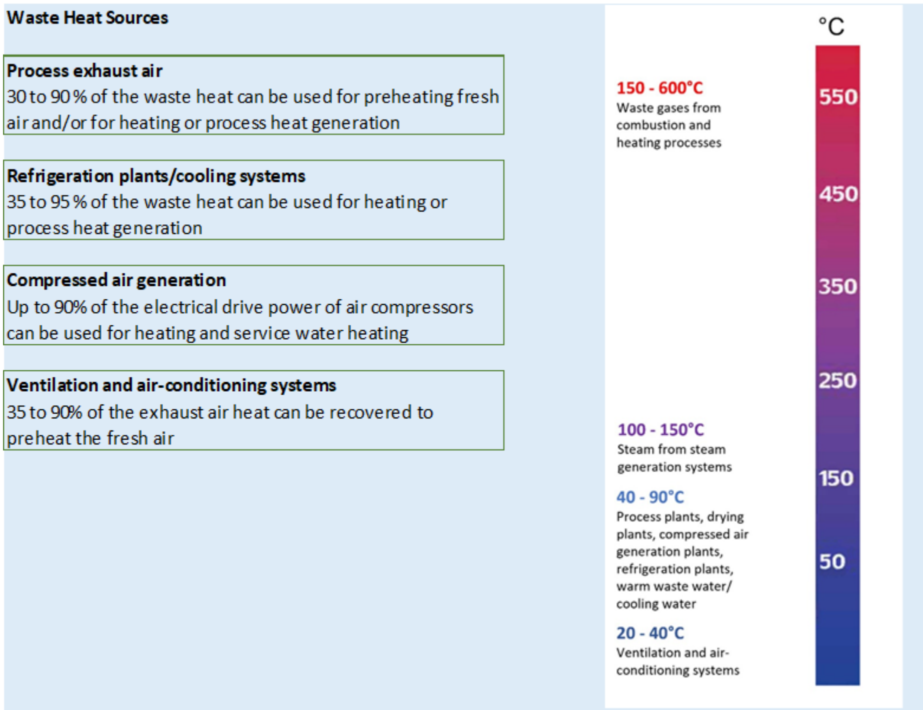


図 2.3-6　産業部門における代表的な廃熱源とその温度レベル

出所：第 2 回日独エネルギー変革評議会資料

表 2.3-5　廃熱の内部利用と外部利用

Internal Waste Heat Utilization (and Prevention)	External Waste Heat Utilization
• Prevention e.g. through thermal insulation or process optimization • Reintegration of waste heat into the same process (heat recovery) • Use of waste heat outside of the process of its origin • Transformation into other useful energy forms (electricity etc.)	• Waste heat that cannot be used internally is transferred to third parties (e.g. neighboring companies)

出所：第 2 回日独エネルギー変革評議会資料

多様な廃熱のポテンシャルを特定し、活用するためには、すべての工業プロセスと、工業プロセスからの廃熱を他のプロセスや建物で利用するための技術について総合的な分析が必要である。廃熱の利用可能性は、すべての廃熱源と、それぞれの熱需要見込みを調査することで特定することができる。その際、以下の基準に留意する必要がある。すなわち、温度レベル、利用可能な熱量、廃熱の連続性、熱供給と熱需要のタイミング、熱媒体、地域条件などである。

2.3.3　技術：現状と今後の傾向

廃熱利用において重要な技術は、①蓄熱技術、②ヒートポンプ、③吸収・吸着式冷凍機、④熱電発電である。温度と用途ごとの適用可能技術を表 2.3-2 に示すとともに、各技術の概要を以下に記す。

表 2.3-2　温度と用途ごとの適用可能技術

Temperature range	**Intended use**			
	Electricity generation	**Production at different temperatures**	**Space or water heating**	**Cooling**
High (> 350°C)	Steam turbine, Stirling engines, thermoelectric systems; heat storage systems	Extraction of higher temperature waste heat from power generation; heat storage systems		
Medium (80 to 350°C)	Organic Rankine Cycle (ORC), thermoelectric systems; heat storage systems	Extraction of medium temperature waste heat from power generation; heat	Local and district heating; Extraction of lower temperature waste heat from	Absorption chiller

		storage systems	power generation; heat storage systems	
Low (< 80°C)		Heat pumps; preheating; heat storage systems	Heat pumps; space heating, domestic water heating; return temperature boosting; heat storage systems	Adsorption refrigeration

出所：第 2 回日独エネルギー変革評議会資料、Topical paper on the potential of waste heat usage in Germany and Japan

蓄熱技術

蓄熱技術は、変動する廃熱の供給とユーザー側の熱需要をうまくマッチングさせるために必要である。廃熱の内部利用では、必要な蓄熱時間は数時間から数日程度であることが多いが、ビルの暖房などでは、数日から数週間、あるいは数ヶ月間、必要なエネルギーを供給できる大型の蓄熱槽の利用が特に注目される。蓄熱装置は、発生した熱エネルギーを蓄える期間によってバッファ型、短期貯蔵型、長期貯蔵型などがある。また、動作原理によって顕熱蓄熱、潜熱蓄熱、熱力学的蓄熱などに分類される。

ヒートポンプ

廃熱の温度レベルが直接使用するには十分でない場合、ヒートポンプを使用することで温度を上昇させることができる。一般的なヒートポンプは約 70°C程度までの温度の熱を供給するが、現在、研究開発プロジェクトでは、適切な冷媒を開発することで、160°Cまでの温度範囲を実現している。一方、吸収式ヒートポンプでは、300°Cまでの温度域が実現可能と考えられている。ドイツなどの中欧での典型的な用途は暖房であるが、産業分野におけるヒートポンプの使用も増加傾向にある。

吸収・吸着式冷凍機

吸収式冷凍機は、圧縮熱を利用した冷凍システムで、建物の冷暖房や、工業プロセスなどに利用されている。エネルギー効率が高く、再生可能エネルギーや廃熱を利用することも可能である。一方、吸着式冷凍機は、COP が約 0.4 と低く、投資コストが高く、重量や構造も大きいため、現状では経済的な運用が難しいとされている。

熱電発電

高温と低温の媒体用の熱交換器と、その間の熱電モジュールで構成されている。効率はまだ低くコストも高いが、可動部がなく、事実上メンテナンスフリーで、コンパクトである利点がある。そのため、既存のシステムに容易に組み込むことができ、今後の技術開発が望まれる。開発要素としては、電解質材料の高性能化、大量生産による低コスト化などが挙げら

れる。

2.3.4　廃熱利用に関する日独の比較

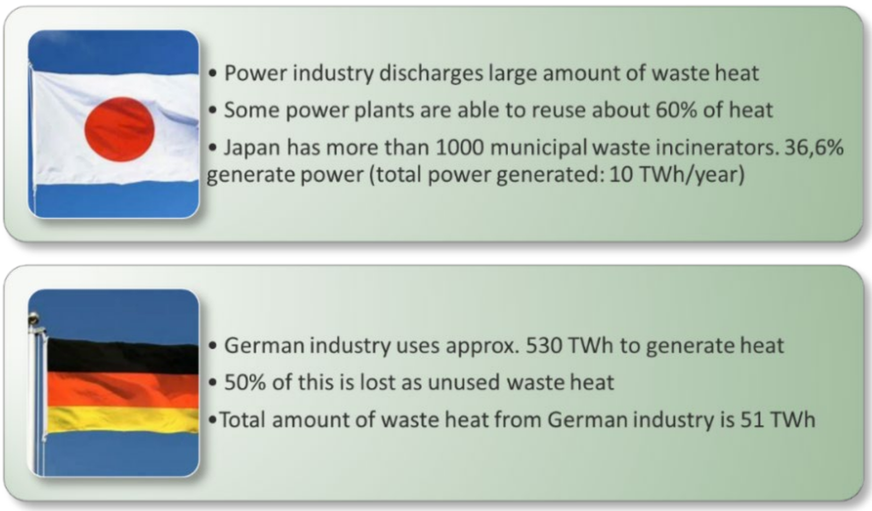
廃熱利用の現状

日本では、発電所から比較的低温の廃熱が大量に排出されている。最新のガスタービンコンバインドサイクル発電では、発電所全体の熱の約 60%を利用することができる。しかし、残りの 40%の未利用廃熱は比較的低温で、その量は膨大である。一方、都市計画法では、住宅地と工業地を分離することが定められており、工場以外の熱の消費先を探すのは難しい。日本では廃棄物の焼却と発電が進んでおり、2020 年度時点の状況は、一般廃棄物総量：4,200 万トン/年、焼却炉の数：1,056 施設、発電機能を有する施設の割合：36.6%、総発電電力量：10,153 GWh/年である。

ドイツでは、約 530 TWh/年のエネルギーを生産・製造工程の熱として使用しているが、その約 50%は未利用の廃熱として失われている。地域熱供給における工業プロセスからの廃熱のシェアは、2018 年には約 1.7%（2,383 GWh/年）であった。また、2020 年には、廃棄物焼却施設からの廃熱のシェアは約 5.5%（7,000 GWh/年）であった。このうち約半分は、廃棄物の組成に基づき、再生可能エネルギーとしてカウントされる。ドイツにおける地域熱供給の半分以上は、熱電併給、つまりガス火力や石炭火力からの廃熱を利用したものである。ただし、火力発電所からの廃熱のほとんどが未利用のままである

以上の比較を表 2.3-3 に示す。

表 2.3-3　廃熱利用の現状に関する日独の比較



出所：第 2 回日独エネルギー変革評議会資料

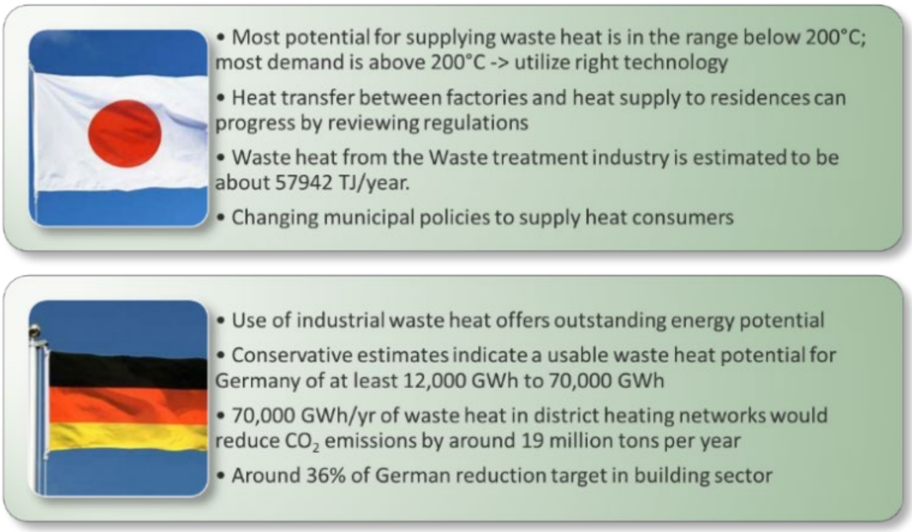
廃熱利用のポテンシャル

日本では、一次エネルギーの約 60%が有効利用されずに環境中に放出されている。うち、

200℃以下の廃熱は全体の 76%を占める。電力業界からは、100～149℃の範囲で 186,851 TJ/年と非常に多くの廃熱が発生している。廃棄物処理業では、比較的高温の廃熱が発生し、その熱量は約 57,942 TJ/年である。石油・石炭産業、非鉄金属産業も 500℃以上の廃熱が大量に発生しており、熱量はそれぞれ、44,889 TJ/年、16,367 TJ/年と推定される。廃熱は 200℃以下が多いのに対して、熱需要の大半は 200℃以上の領域である。そのため、廃熱利用の拡大のためには、高温ヒートポンプなどの低温廃熱の利用技術の開発が重要となる。比較的高温の廃熱については、工場内での利用は進んでいるが、工場間の熱移動、住宅への熱供給は遅れている。また、廃棄物焼却施設は自治体が運営しているため、主な熱利用はプールなどの公共施設の冷暖房に限られ、民間への供給例はほとんどない。これらの問題を解決するためには、技術開発に加えて、都市計画法などの工場立地規制や自治体政策の見直しが重要となる。

ドイツでは、火力発電所、熱電併給プラント、鉄鋼産業の廃熱利用ポテンシャルが大きい。控えめな推計でも、技術的な観点からは、12,000 GWh から 70,000 GWh の廃熱利用できる可能性がある。仮に、年間 70,000 GWh の廃熱を地域熱供給に利用するだけでも、年間約 1,900 万トンの二酸化炭素排出量を削減することができる。これは、ドイツ政府が建築分野で設定した、2020 年から 2030 年の間に 5,300 万トンの二酸化炭素を削減するという目標値の約 36%に相当する。そのため、廃熱の利用は、ドイツの建築分野での温暖化防止目標の達成に大きく貢献することができる。高温ヒートポンプは、化石燃料を使用するボイラーなどと置き換えることができるため、重要な技術と考えられている。また、下水やデータセンターも有望な廃熱源である。比較を表 2.3-4 に示す。

表 2.3-4　廃熱利用のポテンシャルに関する日独の比較



出所：第 2 回日独エネルギー変革評議会資料

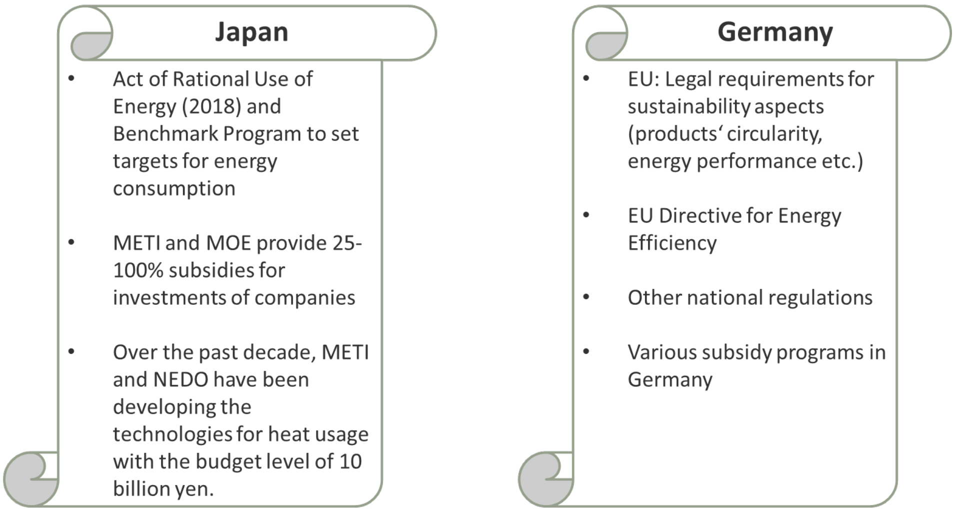
廃熱利用関連政策

日本では、「エネルギーの使用の合理化等に関する法律（省エネ法）」が制定され、1970 年代のオイルショック以降、エネルギー消費効率は 40%向上している。「省エネ法」では、努力目標として、エネルギー消費原単位または電力需要平準化評価原単位を中長期的に平均して年 1%以上削減することを求めている。また、産業部門のエネルギー消費原単位の目標を設定する「ベンチマーク制度」を導入している。その他、関連法規、制度しては「地球温暖化対策の推進に関する法律」や「トップランナー制度」などが挙げられる。インセンティブとしては、経済産業省が、先進的な省エネ設備の導入、各種省エネ設備の導入、ピーク時の電力使用量削減策などに対して、投資額の 25～100%の補助を行っているほか、住宅の断熱や高効率給湯器の導入などに対しても補助プログラムを用意している。また、環境省は、熱交換器、ヒートポンプ、ヒートパイプ、蓄熱システムなどの地域未利用熱利用設備の導入を支援する事業を行っている。研究開発としては、経産省と NEDO で、過去 10 年にわたり廃熱利用に関する事業を実施してきた。

ドイツでは、EU レベルでのエコデザイン指令（Ecodesign Directive）に基づく製品別規制により、製品の循環性、エネルギー性能、その他の環境持続可能性に関する法的要件が設定されている。欧州指令（European Directive）では、エネルギー効率の管理を義務付けている。また、国レベルでの省エネ機器の導入や導入計画について様々な規制を遵守する必要がある。熱の輸送と外部利用については、ドイツ国内では、競争制限禁止法（Gesetz gegen Wettbewerbsbeschränkungen）の第 19 項で規制されている。再生可能エネルギー推進指令（Directive on the Promotion of Energy from Renewable Sources）の改正案では、地域熱供給の運営者に対して、廃熱の供給網への接続義務などについて規定されている。インセンティブとしては、「企業におけるエネルギーの効率化」「効率的な地域熱供給網」「自治体の熱利用計画策定」などに対して、様々な補助制度を導入している。

以上の比較を表 2.3-5 に示す。

表 2.3-5　廃熱利用関連政策に関する日独の比較



出所：第 2 回日独エネルギー変革評議会資料）

2.3.4　日独協力分野に関する提案

日独の協力分野について、提案された内容を表 5-1 に示すとともに、概要を以下に記す。

枠組みと政策

廃熱ポテンシャルの供給と需要を特定することが重要となる。ドイツでは、廃熱のマッピングを行う事業者が多数存在し、そのサービスやノウハウは日本でも活用できる。日独両国は、すでに廃熱利用を支援するさまざまな補助金制度を実施しており、個々の効果についての経験交流が望まれる。

市場デザイン

両国とも大規模な「廃熱市場」はまだ存在せず、電力市場とは対照的に、廃熱を含む熱の自由市場は存在しない。より広範な持続可能な熱市場の一部として、「廃熱市場」の創設を支援するための政治的行動が、日独両国で必要とされている。

インフラストラクチャー

ドイツは地域熱供給網を保有し拡大しつつあるが、日本では一部の北部地域に限られる。一方、日本は、冷房システム、高効率ヒートポンプ、熱電発電などの建設・運用について長い経験を有する。産業界と自治体が参加する廃熱に関する共同プロジェクトや、研究開発の二国間協力などは、双方にとって有益である

技術

産業用ヒートポンプについて、120℃以上の高温域も含む技術開発と利用に向けて、日独の研究機関やヒートポンプメーカーが協力することが有意義であろう。熱の貯蔵について

は、従来からの液体による貯蔵のほかに、固体による蓄熱も適している。潜熱蓄熱（PCM）は、日本での研究成果・知見がドイツにとって有用である。熱電発電については、「産業廃熱利用-日独専門家ワークショップ 2021」のフォローアップとして、すでに日本企業とドイツの研究機関との協力関係のもと進められている。

表 2.3-6　日独協力分野に関する提案

Framework Conditions & Policy	• Identify existing usable waste heat potential (providers and users) 　• For instance: Using waste heat mapping in Japan 　• Encourage suppliers to offer their waste heat (subsidies etc.) • G-J exchange of experience on subsidy programs
Market Design	• In both countries large-scale „waste heat markets“ do not yet exist • Political action is needed on both sides
Infrastructure	• Germany: Mainly district heating grids • Japan: Experienced in construction and operation of cooling systems • Bilateral exchange regarding technologies and systemic concepts to enable further synergy effects for both countries
Technologies	• Industrial heat pumps – Further development through G-J cooperation • Heat storage – Germany can learn from Japanese experience • Thermoelectric generators – Cooperation in research and applications

出所：第 2 回日独エネルギー変革評議会資料

2.4 化石燃料の脱炭素化

2.4.1　化石燃料を取り巻く状況

ロシアのウクライナ侵攻を受けて、ドイツではロシアからのあらゆるエネルギー資源の輸入を禁止する措置を施している。加えて原子力や石炭の使用も抑制する動きもあり、日本と同様に一次エネルギー自給率が低いドイツにとっては、エネルギー供給危機に直面している。つまり、これらの（輸入）禁止令は、ドイツ政府にとって、野心的な気候変動緩和対策とエネルギーの安定供給をどのように両立させるか、という難題を提起している。

ドイツの経済・気候変動対策省（BMWK）は、輸入依存からの脱却と化石燃料の消費量削減（エネルギー効率の向上、再生可能エネルギーの積極的な導入、エネルギー供給体制の多様化など）が優先度の高い解決策であるとし、これによる社会的、経済的影響をシナリオ分析している。ロシア産を含む天然ガスの需要が家庭部門やエネルギー転換部門、産業部門などにどのように配分されているかを精査した上で、ロシア産の天然ガスからの脱却がこれまでに前例のない大きな挑戦であると警鐘を鳴らしている。図 1 のようにドイツはロシア産の天然ガスに半分以上依存していることが分かる。日本は 10%に満たない。

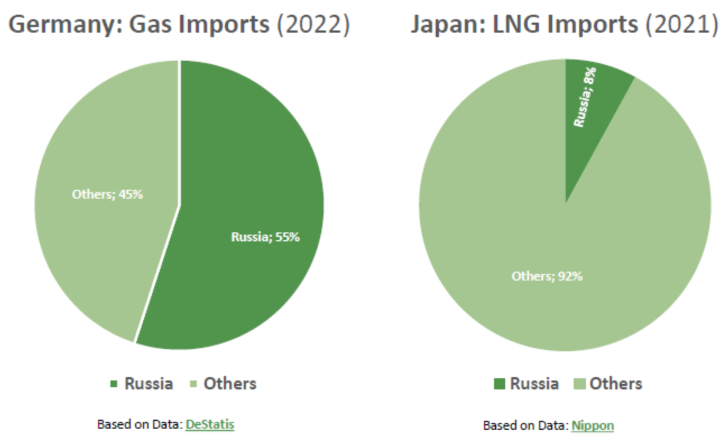


図 2.4-7　ドイツと日本における天然ガスのロシア依存度

出所：第 2 回日独エネルギー変革評議会資料

一方、Ariadne (2022)の調査結果によれば、あらゆるセクターの省エネルギー対策やLNG の多様な国からの追加輸入の組み合わせによって、ロシア産天然ガスの代替は可能だとしている。ただし新たな LNG インフラの構築などについての検討は始まったばかりで、議論の加速が望まれている。なお、Ariadne (2022)の調査はガス供給が中心であり、ガス供給網の収益性や水素社会への転換などについては言及していない。これらの議論は地域自治体の専門家会合レベルで議論されている。

日本は、2030 年の温室効果ガス排出量を 2013 年比で 46%削減することを目標にしている。また、2050 年にカーボンニュートラル社会を実現することを国際公約した。しかし、2011 年の東日本大震災による原子力発電の停止、3 年前から続くコロナウィルス感染症拡大による経済の停滞、そして 2022 年 2 月に始まったロシアによるウクライナ侵攻などにより、エネルギー価格の高騰を招くなど経済に大きな影響が及んでいる。

日本は周囲を海で囲まれ、自国のエネルギー資源に乏しい。日本はドイツ以上に化石資源や化石燃料を海外からの輸入に頼っており、一次エネルギー自給率は 12%しかない（図 2.4-2）。

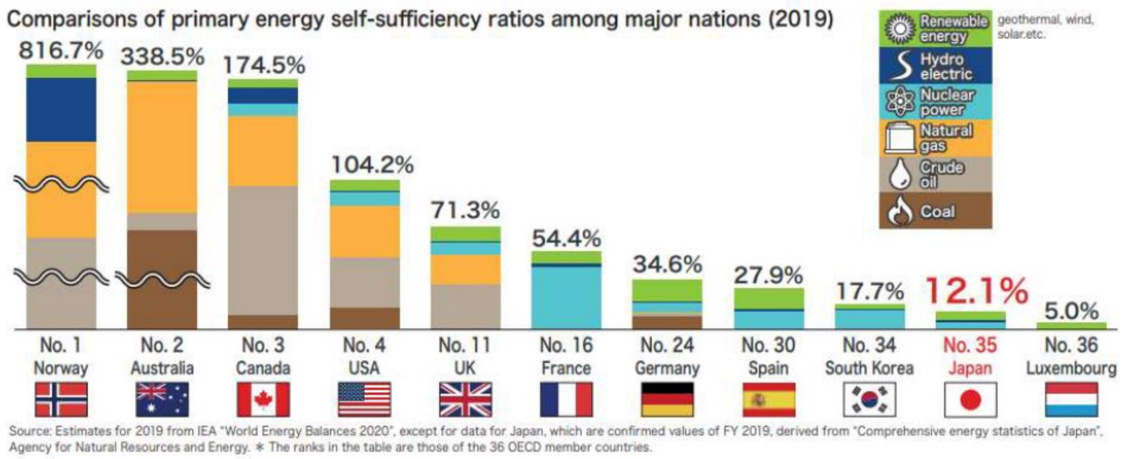


図 2.4-8　各国の一次エネルギー自給率の違い

出所：第 2 回日独エネルギー変革評議会資料

海外からの輸入に依存しているドイツや日本は世界のエネルギー変動の影響を受けやすい。世界各国で発生している電力需給の逼迫やエネルギー価格の高騰などは両国でも見られる。エネルギーの安定供給の確保は、国民生活や企業活動の根幹であるため、これは重大な課題と捉えられている。そのため、徹底した省エネルギー、製造業の構造転換（燃料転換や原料転換）、再生可能エネルギーの積極的な導入、原子力の活用、水素やアンモニアなどの CO2 フリー燃料の導入促進、資源やエネルギー確保に向けた国際連携の強化、カーボンリサイクルや CCS の導入促進などを進めている。

2.4.2　エネルギー構造

ドイツも日本も一次エネルギー供給率が低い。日本のエネルギーフローを例に取ると（図 2.4-3）、一次エネルギー消費量の約 85%が化石燃料であり、これらの燃焼が CO2 排出源になっている。発電に消費されるのは一次エネルギーの約 3 割であり、ドイツもほぼ同じ割合である。つまり再生可能エネルギーで全ての電源を CO2 フリーにしても、その量は一次エネルギーのたった 3 割であり、残りの 7 割に対する対策が必要になる。この 7 割は石油や天然ガス、石炭を由来とする原料や燃料であり、産業部門、運輸部門、民生部門で消費されている。

ドイツは、カーボンニュートラルの実現に向けて、2022 年夏に再生可能エネルギー法（EEG）と洋上風力発電法を改正した。これによると、2030 年までに陸上風力 115GW、洋上風力 30GW、PV システム 215GW を導入する（図 2.4-4）。そしてドイツでは 2030 年までにドイツの電力消費の 80%を再生可能エネルギーで賄い、2035 年までに石炭から脱却し、2045 年にカーボンニュートラルを実現することを目標としている。これには電力網と水素網の整備、産業、ビル、運輸にグリーン電力を供給するための水電解槽、電気自動車、ヒートポンプ、電極ボイラー、蓄電池などの様々な技術とシステムが必要である。

日本の場合は平地が少なく、良い風況地や日照地が限られているため、再生可能エネルギーの導入量には限界がある。日本海側の積雪、台風の襲来などの自然現象や、再生可能エネルギーに適した場所が地方に偏在しており、人口密集地（エネルギー消費地）との距離があるなど、課題は山積みである。

ドイツも日本もエネルギー自給率が低いため、海外からの再生可能エネルギーの輸入も視野に入れる必要があり、水素、アンモニア、メタノール、MCH（メチルシクロヘキサン）などのエネルギーキャリアを輸出入するための様々な検討が実施されている。

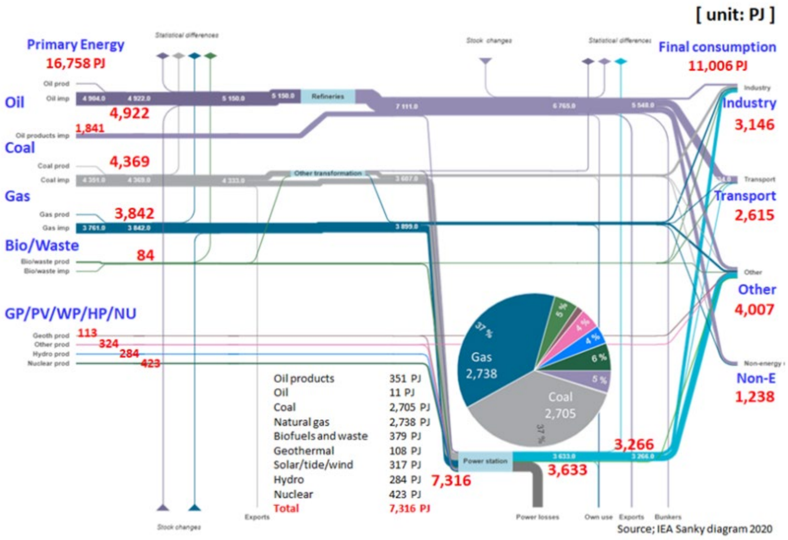


図 2.4-9　日本のエネルギーフロー

出所：第 2 回日独エネルギー変革評議会資料

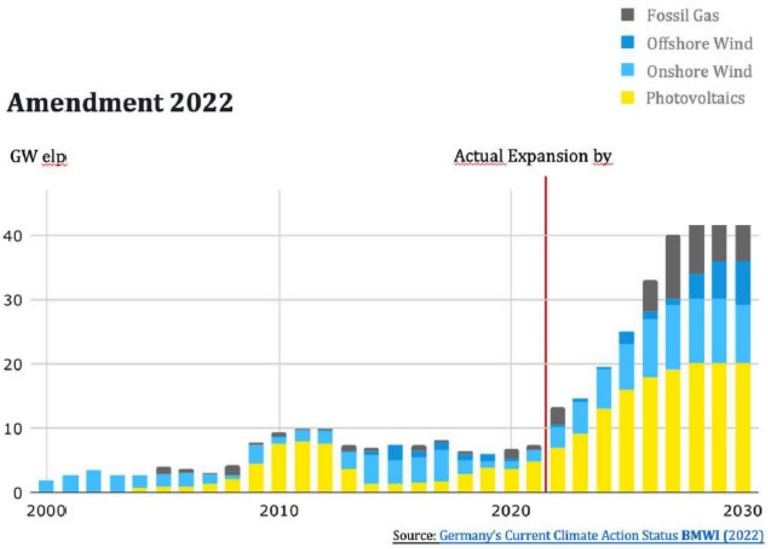


図 2.4-10　ドイツにおける再生可能エネルギー導入シナリオ

出所：第 2 回日独エネルギー変革評議会資料

2.4.3　セクター別の取り組み

運輸部門

運輸部門は、ガソリンをはじめとする石油製品（ガソリン、軽油、ジェット燃料など）に大きく依存しており、ドイツも日本もその割合は 90%以上を占める。

ドイツでは運輸部門に対して可能な限り e-mobility（BEV も含む）を導入する方針である。ドイツの自動車台数は日本の約半分（2022 年には 4,850 万台）であるが、平均車体重量は SUV への移行から重量化が進んでおり、グリーン電力の需要が増加すると危惧されている。ドイツ環境庁は車両の小型化とともに、公共交通機関、自転車、カーシェアリングの積極的な活用を提案している。

日本も積極的に電気自動車（BEV）や燃料電池自動車（FCV）の導入を図っているが、普及量はとても少ない。BEV や FCV の導入には、電力や水素の供給が欠かせないが、例えば日本で太陽光発電による BEV への電力供給を想定すると、日本に現存する太陽光発電設備の約 1.5 倍が必要にある。FCV ならば、日本政府の 2030 年における導入目標以上の水素が必要になる。

その他、バイオマスや廃食用油、CO2 などから製造できる合成燃料（e-fuel）を利用する方法もある。E-fuel の場合、その CO2 源が化石燃料であるならば、カーボンニュートラルにならないことから、大気から CO2 を回収する技術（DAC）が必要になる。

民生（家庭・業務）部門

ドイツでは建築部門の最終エネルギー消費量が年々増加していることから建築物エネルギー法（GEG）が 2024 年 1 月に改正される。新しく設置されるすべての暖房設備の 65%が再生可能エネルギーによるものと法律で規定される。

日本でもエネルギー完結型の ZEB や ZEH などが第 6 次エネルギー基本計画の中に記載され、2030 年以降に新築される住宅・建築物については、ZEH・ZEB 水準の省エネルギー性能を持つものが求められる。

民生部門はもっとも電化が進んでいる部門であり、電力を再生可能エネルギーで供給することが非常に重要である。電力以外のエネルギー消費は、主に石油とガスによるものであるが、そのほとんどは暖房用などに消費されている。石油製品やガス製品を脱炭素化するには、バイオマスや廃食用油、CO2 からの合成燃料の活用が考えらえる。

産業部門

産業部門は、ドイツも日本も同じで、様々な分野が混在しているため、分野によって化石燃料の使われ方が違う。製鉄分野では、高炉・転炉法が世界の製鉄法の主流であるが、この方法では石炭由来のコークスを多く消費するため、CO2 排出量が多い。コークスの消費量を削減するため、水素還元製鉄や直接還元製鉄などが検討されている。セメント分野では、クリンカ焼成時に大量の CO2 を排出するため、日本では石灰石に替わる CO2 フリ

ーな原料を使用する方法や、セメントからコンクリートを製造する際に使用する骨材にCO2を利用した材料を使用する方法、そしてコンクリートの強度を制御するためコンクリートにCO2を吸収させる（養生プロセス）など、様々な実証としての試みが実施されている。化学産業（石油化学）は幅広い分野であるため、一般解はないが、CO2排出源が電力、原料、熱源（蒸気）であるため、それらをCO2フリーなものに代替していく必要がある。再生可能エネルギー、バイオマスや廃プラスチックなどを利用した固形燃料、アンモニア、MCHやメタノールなどのエネルギーキャリアを利用した液体燃料、そして水素やバイオガス、合成メタンなどを利用した気体燃料の活用法がある。ただし燃料の製造時や、エネルギーキャリアの燃焼時（発電時）にはCO2が発生してしまうため、CO2を回収して再度燃料を製造するなど、カーボンリサイクルの考え方を導入することが重要である。

2.4.4　政策動向

欧州とドイツの脱炭素化戦略は、国際的な気候政策の進展や、米国のインフレ抑制法（IRA）などに大きな影響を受けている。2023年2月に欧州委員会はグリーンディール産業計画を発表し、ネットゼロのために必要な技術や製品に対し、その開発や製造能力を拡大する。対象となる技術は、バッテリー、風車、ヒートポンプ、太陽光、電解槽、CCSなどが挙げられている。

日本は2021年に第6次エネルギー基本計画を発表した。2030年に想定する電力供給量のうち、再生可能エネルギーはその36～38%を占める。水素やアンモニアによる発電電力量も全体の1%にする。さらに同年に発表されたグリーン成長戦略によると、水素は2030年に最大300万トン、2050年に2,000万トン程度を導入する。アンモニアは、2030年には、国内需要として年間300万トン、2050年には年間3,000万トンを導入する。合成メタンについても、2030年に既存インフラに合成メタンを1%注入し、2050年には90%注入することを目標にしている。こうした目標を達成するために、事業者のインセンティブの創出やサプライチェーンの構築を早期に実現するため、官民協議会が発足し、活発な議論が行われている。

2.4.5　日独比較

ドイツと日本の化石燃料に関する類似点と相違点を表2.4-1にまとめた。

ドイツと日本には共通点が非常に多く、エネルギー自給率の低い両国ならではの対策が練られている。加えて、2030年以降のシナリオは両国とも明確にはされておらず、カーボンニュートラル社会の実現に向けてのアプローチについては、再生可能エネルギーやカーボンリサイクルなどを筆頭に手探りの対策が実施されている。

ドイツと日本には地理的な違いがあり、隣国と陸続きであるドイツは多様なエネルギー輸入が可能であるが、島国である日本は船舶輸送に頼らざるを得ない。カーボンニュートラ

ルに向けた政策についても若干の違いが見られ、ドイツの政策は再生可能エネルギーの大量導入に軸足を置いているのに対し、日本は CCU（CO2 有効利用）燃料やエネルギーキャリアなど様々な燃料を活用するような政策が練られている。

表 2.4-6　ドイツと日本の化石燃料に関する類似点と相違点

Similarities	Differences
• High energy prices • Mid-century net-zero targets • Finding ways forward to reach net-zero targets specially beyond 2030 • Limited domestic resources (import dependent) -feedstocks, synthetic fuels, renewable resources (energy carriers*) *energy carriers: hydrogen, ammonia, etc. • Expansion renewable energies • Focus on CO_2 recycling	• Land connections to other countries 　• Germany: Varied supply 　• Japan: Only by ship • Dependence on Russian natural gas • Energy mix and scinario by sector 　• Aggressive use of renewable energy in Germany 　• Various fuel use based on decarbonization and carbon recycling in Japan

2.4.6　まとめ

将来のカーボンニュートラル社会の実現に向けて、ドイツと日本はともに協力し、学び合い、そしてお互いの強みや弱みを理解し合った上で、お互いの国力を強化する必要がある。化石燃料の分野における両国の類似点と相違点から、お互いを知り、学び合うべきポイントは大別すると以下の 4 つである。

① 化石燃料を代替する燃料に何に求め、経済性や環境性を確保できる輸入要件は何か？
② 燃料の用途により燃焼後に CO2 を分散して排出してしまう場合は、CO2 フリー燃料、電化、DAC や CCS などを考える。
③ カーボンニュートラル社会を実現するために必要な新しい技術やシステム、インフラなどの開発の加速。
④ 将来のカーボンニュートラル社会実現のために政策決定された CO_2 排出量の削減目標に対して、現実との将来の目標とのギャップを正確に理解し、特に 2030 年以降のトランジション期間にやるべきことを、透明性をもって提示する。

こうした行動を起こす事と同時に、燃料を取り巻く世界の情勢や市場、貿易協定の動向についての注視を怠ってはならない。また再生可能エネルギーは世界中で開発が活発化しており、コストも下落傾向にある。エネルギーキャリアや合成燃料、CCU 燃料などは再生可能エネルギーと密接な関係にあることから、輸出入先候補へのアプローチなども不可

欠である。

第 3 章　日本のエネルギー政策への提言

ここでは、ドイツの最近のエネルギー・環境政策動向を概観するとともに、ドイツとの共同研究成果を踏まえて日本のエネルギー政策への提言を検討する。

3.1　ドイツの政策動向

最近のドイツの政策動向について、「ロシアによるウクライナ侵略を契機とした変化」と「水素戦略を巡る変化」の二つを取り上げて整理する。

ロシアによるウクライナ侵略を契機とした変化

ドイツは野心的な気候変動目標の設定と対策で知られているが、2022 年 2 月に始まったロシアによるウクライナ侵略以降は、従来と異なる情勢も見られた。「脱原子力」と「脱化石燃料投資」という、ドイツを象徴する二つの政策における変化である。

第一に、原子力発電停止計画の延期である。従来の計画では、2022 年中に全ての原子力発電所を停止することとなっていた。しかし、天然ガス不足による電力需給ひっ迫への懸念から、暫定措置ながら、2023 年 4 月半ばまで最後に残った 3 基の運転を延長すると決めた。ドイツの原子力政策はこれまでも紆余曲折を経てきた。福島第一原子力発電所の事故以降は脱原子力が太宗となっていたが、現実のエネルギー供給危機を前に運転延長を認めざるを得なかったのであろう。なお、2023 年 4 月半ばの停止方針に変わりのないことが報じられている [4]。

第二に、LNG 輸入への投資である。従来のドイツの政策では、化石燃料投資は将来の CO2 排出をロックインするものであり、また座礁資産化するリスクが高いため推奨の対象とはならなかった。しかし、ロシアからの天然ガス輸入を減らすという政策、あるいはロシアの戦略的な輸出量削減から、供給を確保するために LNG 輸入に踏み切らざるを得なかった。これまでドイツは LNG 輸入設備を持っておらず、そのため政府主導で浮体式の LNG 輸入インフラを短期間のうちに整備し、また輸出国との輸入契約を取りまとめた。天然ガスはドイツの産業用燃料・原料や建物の暖房用燃料として多用されており、供給不足は産業活動の停止や最悪の場合は人命にも関わる一大事である。そのため、緊急避難措置との位置づけではあるが、政府が化石燃料投資を先導するという大きな変化をみせた。

これらの事例から、ロシアによるウクライナ侵略がドイツのエネルギー政策にきわめて大きな影響を及ぼしたことが分かる。前述のとおり「脱原子力」と「脱化石燃料」はドイツを象徴するエネルギー政策であったが、エネルギー供給の危機は、これらを翻らせるほどに

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[4] 日本経済新聞, 2023.3.16

重大であった。
　また、非常事態を前にしたドイツの対応は、我々に 3E[5]のバランスの重要性やエネルギーミックスの意義、移行期のエネルギーシステムの強靭性への考慮の必要性を再認識させてくれる。脱炭素という方向は正しく長期政策の軸であり続けるものの、十分な代替供給やバックアップを用意しないまま進める性急な構造転換は 3E のバランスを崩し、過渡期に脆弱な状態を生み出す危険性のあることを証明した。そして、今回のような危機がいつどのような形で再び訪れるかを予測することはできず、リスクを想定した構造転換の道筋を考察することが求められる。

水素戦略を巡る変化

　ドイツは 2020 年 6 月に The National Hydrogen Strategy を策定した。産業や大型トラックなど相対的に脱炭素化が困難な部門の対策を急ぐ必要があり、また今後ますます増えていくことが必至の再生可能電力の需給調整機能として水素への期待が高まっていることから、戦略の見直しを進めている [6]。
　検討が進められている新たな戦略では、引き続きグリーン水素を主軸としつつも、ブルー水素を移行期の重要な選択肢として位置づけ、これも推進する方向のようである。2020 年の戦略ではブルー水素にはほぼ触れておらず、現時点で断定はできないものの、現実的な中継ぎ役としてブルー水素の役割が見直されているのかもしれない。
　グリーン水素の製造能力という点では、2020 年の戦略では 2030 年までに 5GW の水電解槽を設置するとしていたが、目標を 10GW に引き上げることが検討されている。最近行った市場調査によると、計画中の水電解槽の容量を積み上げると 2030 年には十分に目標を達成可能な見通しとなっているようである。
　一方の需要では、製鉄における高炉法から水素を用いた直接還元法への転換や、燃料電池式大型トラックの導入など、2030 年に 60TWh を想定している。10GW の水電解能力では 60TWh の需要を満たすことはできず、輸入が不可欠となる。輸入では、北海やイベリア半島、更には北アフリカからのパイプラインを用いた方法を想定している。
　これら需給両面の創出という点では、H2Global と称する方法を採る。供給側では 1 年契約の国産水素と 10 年契約の輸入水素を対象に、需要側ではアンモニアやメタノール、航空用合成燃料を対象にそれぞれ入札を行う。供給側と需要側では価格に差が生じるため、これを政府が最大 9 億ユーロの予算で補助する。
　国内の水素輸送インフラという点では、欧州連合（EU）の支援プログラム [7]の認定を受け

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[5] 3E：Energy security（供給安定性）、Economic Efficiency（経済効率性）、Environmental sustainability（環境適合性）

[6] Dr. Felix Matthes, 2023.3.1

[7] Important Projects of Common European Interest（欧州共通利益に適合する重要プロジェクト）

た 5 つのプロジェクトを皮切りに、2050 年までにドイツ全土に水素パイプライン網を普及させる構想がある。多くは、既存天然ガスパイプラインの転用を想定している。

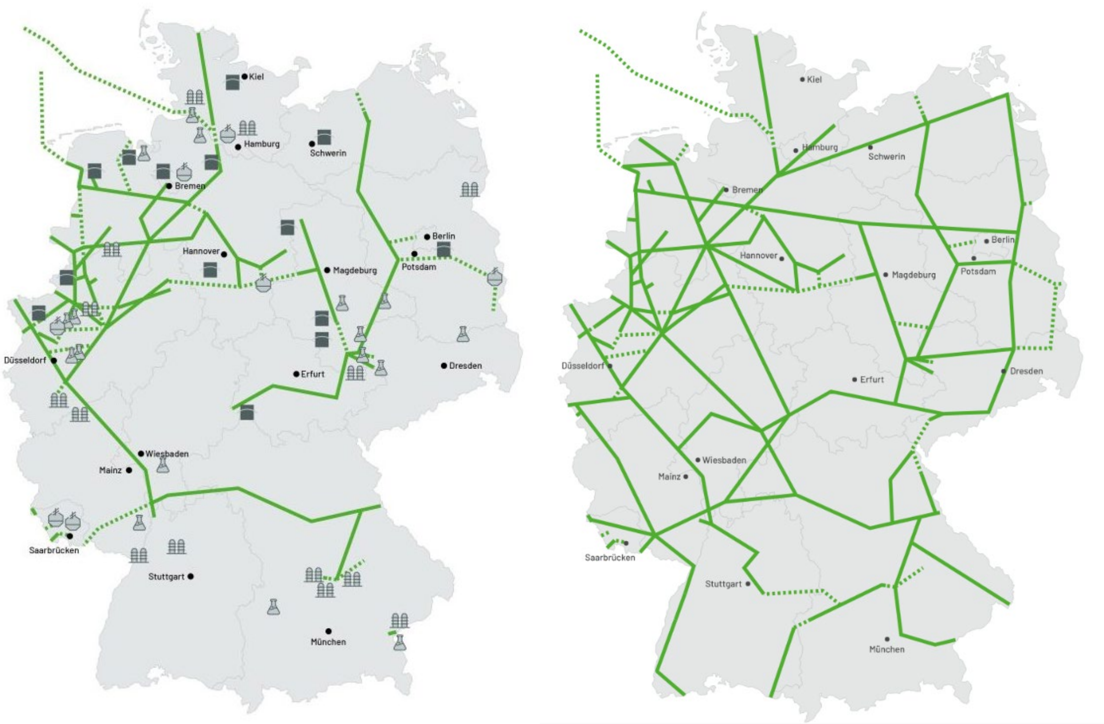

図 3.1-1　水素パイプラインの構想（左：2030 年、右：2050 年）

注：実線は既設天然ガスパイプラインの転用、破線は新規建設を表す。

出所：FNB Gas

最後に、今後検討を深める分野の例として次の点を挙げている。

・水素の持続可能性基準の策定
・水素の導入分野の整理
・水素インフラの基準策定
・水素輸入に向けた国際協調
・水素輸入の地政学的な意味の考察

日本は世界に先駆けて 2017 年に水素基本戦略を策定した。その後、多くに国が水素戦略を策定して推進に向けた取り組みを始めたが、ドイツでも水素に対する関心が更に高まっているようである。需給の創出や輸入を含むサプライチェーンの構築など、日独の水素戦略には共通の課題があり、引き続き相互学習の機会が生まれ得る。

3.2　日本のエネルギー政策への提言

ここでは 4 つの研究テーマの成果を踏まえ、日本のエネルギー政策への提言を整理する。

① 建物の既築対策と外皮性能の強化

これまでの日本の建物の省エネ対策の中心は新築、設備であったが、既築の対策と外皮性能（断熱）の更なる強化が期待される。建物の寿命は長く、今この瞬間にも建てられている新築建物は 2050 年を超えて存在しつづける可能性が高い。そのため、十分なゼロエミッション性能を備えていない多数のストックに対策していくことが不可欠である。しかし、既築対策は居住者・所有者に少なくない経済的負担を求めることになるため、必要な投資を施すのは容易でない。補助金といったインセンティブを与えることや、所有者によるゼロエミッション改修に関する情報へのアクセスの拡大、建築業者の教育によるノウハウ向上、建物のゼロエミッション性能の評価と価値化、といったことが考えられる。

外皮性能については、地域の気候に配慮しつつ、段階的に基準を強化していくことが考えられる。また日本においては地方自治体の役割も大きいことから、カーボンニュートラルに向けた数値目標を含む工程表を、政府と地方自治体が共通認識として堅持することも効果的であろう。

加えて、建築段階の二酸化炭素排出（embodied carbon）の管理強化も不可欠である。Embodied carbon も含めたライフサイクルでの二酸化炭素排出の評価手法の整備やその普及に向けた取り組みが行われており、これを着実かつ速やかに進めることが求められる。

② 競争力に配慮した（石油）化学産業の脱炭素化

化学産業の脱炭素化は科学的には現在でも可能であるが、経済合理性がない。化学産業は国際競争に晒されており、生産コストの上昇は市場の喪失を意味する。このことは、天然ガス価格が上昇したドイツにおいて化学産業の退出が起こったことからも明らかである。脱炭素に向けた取り組みは不可欠であり、また早期にこれを実現することで、世界全体がカーボンニュートラル（CN）に向けて邁進する際には先行者利益を得ることができる。一方で、脱炭素の追加コストが過度なものとなれば、CN への移行期には逆に産業を壊すことになりかねない。そのため化学産業の脱炭素化の速度は、潜在的な競合国のそれとの比較で注意を払う必要もある。対策の一つは欧州が採る炭素国境調整メカニズム（CBAM）であろうが、貿易制限的な措置には慎重な検討が必要である。

化学産業が競争力を維持しつつ脱炭素化を実現するには、極力安価に脱炭素燃料・原料を調達する必要がある。国内で入手可能な再生可能電力やバイオマスはもとより、輸入が必要になると考えられる水素（および水素を原料とした各種合成物）の低コスト化に向けて、技術開発や市場拡大の支援が可能である。

③　廃熱利用

未利用の廃熱は大量に存在しているものの、廃熱の発生地と需要地を結びつけることが地理的、技術的に課題である。日本では廃熱の多くが発電所などで発生しているが、利用可能な高温廃熱は既に多くが有効活用されていると考えられ、残された低温排熱は工業用には利用が難しい。また、土地の利用区分から工業地帯と商業地・住宅地はそもそも離れており、廃熱を商業施設や住宅まで輸送することは経済性を得にくい。こうしたことから、身近にある廃熱を地産地消することが合理的であると考えられ、この点で、ドイツで行われている廃熱のマッピングが参考となるかもしれない。

技術面では産業用の高温ヒートポンプ技術や、蓄熱技術の開発が行われているが、これらの商業化によって廃熱の利用可能性を広げることができる。特にヒートポンプ技術は、脱炭素に向けて需要の電力化を進めることになるなか、世界で大きな市場が期待できると考えられる。

④　化石燃料の脱炭素化

カーボンニュートラル（CN）は世界が共有する目的であるが、その実現には時間を要する。途上国ではエネルギー需要が増え続ける可能性が高いことを踏まえれば、世界の化石燃料需要はしばらく拡大し続けることも十分にある。このような状況下で化石燃料投資を止めれば供給力の低下によって需給ギャップが拡大し、世界は不安定なエネルギー供給と価格の高騰に悩まされ続けることになる。エネルギー供給不足を起点とした経済危機は今まさに世界が経験していることであり、こうした状態が健全であるはずもない。負担能力の高い一部の国はこの状況をしのぐこともできようが、低所得国はそうはいかない。世界の安定を考えれば、当面化石燃料の安定供給を維持するための投資は不可欠であると考えざるを得ない。

一方、長期的には化石燃料の役割が低下していくのは必然である。CN を目指すというエネルギーシステムの大転換の只中にあっては、将来見通しの不確実性から企業が化石燃料投資をためらうとしても仕方がない。これを回避するには、政府が化石燃料の必要性を明確に示すことで化石燃料投資のリスクを緩和するとともに、将来化石燃料を脱炭素利用するための素地を整えることが求められる。すなわち、ブルー水素（および水素を原料とした各種合成物）の市場やサプライチェーン構築支援である。先に見たとおり、ドイツでも水素輸入を検討している。地域は異なるものの、世界の水素市場構築に向けて協調する余地があるだろう。

付録１．建物の脱炭素化戦略

付録２．エネルギー多消費産業の脱炭素化 – （石油）化学産業 -

付録３．廃熱利用

付録４．化石燃料の脱炭素化

German Japanese Energy Transition Council

Strategies, concepts and measures for decarbonizing the building stock by 2045/50

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ECOS

IEE JAPAN

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List of Abbreviations, Units and Symbols

Abbreviations

BEV	Battery electric vehicle
BMWK	German Federal Ministry of Economic Affairs and Climate Action
BMU	German Federal Ministry for the Environment, Nature Conservation, Building and Reactor Safety
EEA	European Environment Agency
ETS	Emission Trading Scheme
Fig.	Figure
GDP	Gross domestic product
GHG	Greenhouse gas
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
LCA	Life-cycle assessment
NECP	German Federal Government's Integrated National Energy and Climate Plan
SMEs	Small and medium-sized companies
Tab.	Table
WI	Wuppertal Institut für Klima, Umwelt, Energie GmbH

Units and Symbols

$	US dollar
%	Per cent
€	Euro
°C	Degrees Celsius
bn	Billion
CO_2	Carbon dioxide
CO_2 eq.	Carbon dioxide equivalents
Gt	Giga tonne
kg	Kilogram
km	Kilometre
kt	Kiloton
kW	Kilowatt
kWh	Kilowatt hour
m	Million
MJ	Megajoule
Mt	Metric tonne
Nd	Neodymium
Nm^3	Normal cubic metre
p.a.	per annum
pkm	Passenger kilometres
ppm	Parts per million
s	Second
t	Tonne
vol%	Percentage by volume

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Executive Summary

To reach the climate neutrality goals in Japan (2050) and Germany (2045), ambitious policy measures are crucial. Particularly in the building sector the potential for greenhouse gas (GHG) emission reduction is important: Through better insulation, the energy needed for floor heating can be reduced significantly, the installation of PV-systems on the rooftop or the switch from fossil fuel-based heating systems to heat pumps running on renewable electricity further facilitate the decarbonization of the building sector. While environmental-sound constructions of new buildings are important, it is equally/even more important to foster renovations in the existing building stock. At the same time, renovations are also challenging because of lacking information, financial resources and the difficulty to impose regulations.

In Germany, a policy called first *Heat Insulation Ordinance* setting new energy efficiency standards for German buildings was first introduced in 1979 and revised/tightened numerous times ever since. Following a number of developments in Germany and the EU in 2021 (among which the revision of the climate protection law, the European Green Deal/fit for 55, Russia's war of aggression against Ukraine) the newly inaugurated German government put high priority on the decarbonization of the building sector. In Japan, on the other hand, the Top Runner program that had been put into place in 1998 to improve the energy efficiency of commonly used electronic appliances, was adapted to the building sector in 2017 as *Residential Top Runner System*. More recently, the Japanese government announced presented the roadmap of the *Green Transformation* (GX Transformation) that also includes measures to foster the energy performance of buildings. Against this background, comparing the situation in both Japan and Germany can be beneficial to better understand the deviant situations of each country and learn about best-practices.

Based on their geographical characteristics, Japan and Germany face partly different challenges: While Germany is prone to colder and longer winter, most parts of Japan heavily suffer from hot summers. In addition, the energy consumption also differs due to rather cultural factors, such as the habit of just heating those rooms actively used as is common in Japan, contrasting the practice of heating the entire housing with a central heating system in Germany. On the other side, most Japanese practice bathing on a daily basis which contributes to a large share of energy used to produce hot water. At the same time, both countries provide a high level of technology standards.

To reduce the energy consumption in the building sector the governments of both countries set standards/energy efficiency levels. While in Germany it is now mandatory to present the Energy Performance Certificate (EPC), the consumption performance label in Japan is voluntary. Contrary to Japan, where the installation of rooftop PV depends on the ruling of the municipalities, the integration of renewable energy will become mandatory for German buildings. Overall, the focus on the Japanese policies lies rather on improving the energy efficiency of appliances than the building envelope.

Both countries still need to increase their efforts in increasing the annual renovation rate while also phasing out fossil fuel boilers by replacing them e.g., by heat pumps. Another challenge for both countries concern the building floor space and the embedded carbon emissions related to constructions. Finally, the retrofit market must become more attractive through e.g., the active usage of Energy Passports and One-Stop-Shop service.

1 Introduction

Based on the Paris Agreement adopted in 2015, Japan announced in October 2020 that it aims to achieve carbon neutrality by 2050. In addition, consistent with the long-term goal of carbon neutrality in FY2050, Japan declared its ambitious goal of reducing greenhouse gas (GHG) emissions by 46% from FY2013 level by FY2030, and expressed its determination to continue to take on the challenge of achieving a further 50% reduction. Currently, discussions and efforts are underway to find a way to achieve this reduction target.

In 2019, the German government agreed on a climate protection law that specifically set sector targets to reduce the GHG emissions in the fields of energy, industry, transport, building, agriculture, waste (and others). The overall goal was to reach climate-neutrality in 2050. Following a ground-breaking ruling of the German constitutional court in April 2021, the law was then revised. To reach climate neutrality already in 2045, as is prescribed by the revised climate protection law, the sector targets and interim targets have also been tightened. In addition to the German legislation, new initiatives on the European level further trigger the policy developments in Germany: Based on the European Green Deal, the EU put in place the fit for 55 plan that seeks to reduce the Member States' GHG emissions by 55% until 2030. Among the measures considered, the recast of the EU Directive on the energy performance of buildings (EPBD) and the creation of a second European Emission Trading Scheme (ETS 2) for the transport sector and the building sector are noteworthy, as the share of GHG in these sectors is particularly large. In light of Russia's war of aggression against Ukraine, the new government, inaugurated in December 2021, launched an ambitious program to decarbonize the German building sector.

Established in 2016, the German-Japanese Energy Transition Council (GJETC) strives to promote bilateral cooperation between Germany and Japan on energy transition. While the most recent studies focused on approaches to decarbonizing the steel industry, challenges in the utilization of storage batteries (including those for automotive use), and long-term energy scenarios, an output paper in 2020 already compared the energy efficiency in buildings in both countries with a particular focus on heating and cooling. One important finding of this output paper was that further efforts in the building sector are needed to improve the energy efficiency of buildings in Germany and Japan. Following the more ambitious climate protection targets in both countries, this study seeks to analyze the German and Japanese policies put in place to accelerate the decarbonization of the building sector. The decarbonization of the vast number of buildings that both Japan and Germany are facing will be effective enough to achieve the GHG reduction targets of both countries, and should continue to be discussed among experts and developed into a discussion among policy makers.

This report examines and compares the characteristics of the building stock and existing policies in both countries (chapter 2), as well as new strategies and policies that are planned or discussed to achieve energy conservation and decarbonization of buildings (chapter 3). The current shape of buildings, especially houses, is greatly influenced by the size of the country, the natural environment surrounding the country, the natural resources available, and the lifestyle and cultural ideas that have been passed down and taken root over time. Therefore, it might be difficult to compare them and the corresponding strategies and policies with the same yardstick (chapter 4), but through joint research, we aim to find each other's advantages and challenges and to develop useful and concrete policy recommendations (5) that will contribute to decarbonization policies in both countries.

1. Context: Building Stock Characteristics and Existing Policies

In order to lay the foundation for the analysis of potentials for decarbonizing the building stock and of policies to harness the potentials, this chapter presents the characteristics of the building stock as it has emerged in both countries until now.

Following a description of the development of the building stock's size and growth (2.1), the average of building stocks, and structure of the buildings' age (2.2) as well as the energetic characteristics based on the construction material (2.3) are addressed. Subsequently, current data for the average building energy intensity (2.4) and the overall energy consumption (2.5) are presented as background data that might contribute to comprehend differences in the policy development of both countries.

2.1.1 Germany

Out of a total of 21,356,912 buildings, the residential buildings account for 19,375,912 buildings compared to 1,981,000 non-residential buildings. More than half (75%) of the residential buildings are detached or semi-detached houses that are mostly owned by families living there (Dena 2022). Around 60% (140,000) buildings out of the non-residential building stock are owned by the public sector (federal government, federal states, municipalities, institutions/corporations under public law), among which mainly schools, day care centers and other care facilities (Dena 2022).

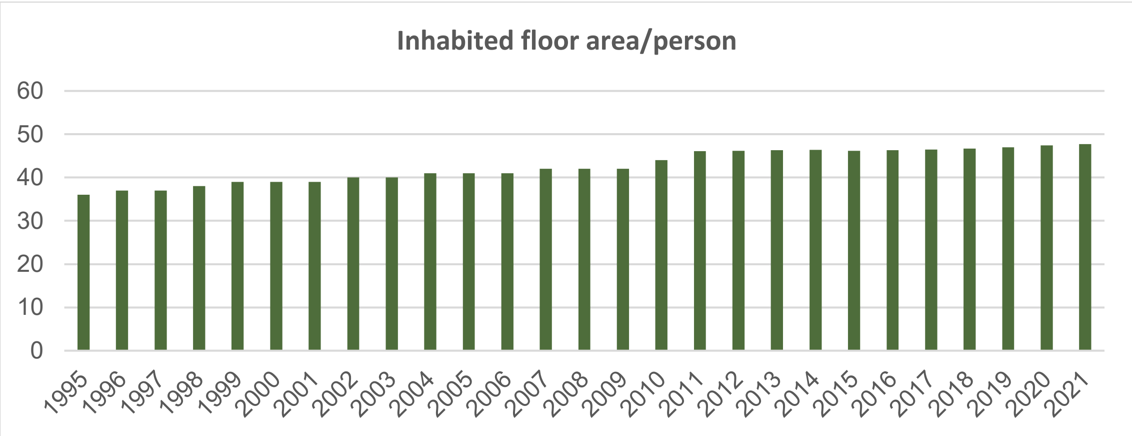

Figure 2-1: Inhabited floor area per person

(Source: Destatis 2023)

The population of Germany amounts to 84.1 million as compared to the one of Japan amounting to 125.7 million inhabitants. In Germany, the average per capita floor area has gradually increased from 1990-2009 and now is 47.7 m^2. One possible reason for this considerable increase since 1990 is related to a growing demand for larger apartments and houses, while the number of people living in the same households is going down (UBA 2022/Statistisches Bundesamt 2022). After 2010, the average per capita floor area has been considerably stable due to increased immigration (dena 2022).

A large proportion of the existing housing stock in 2021 were single- and two-family houses (16,105,498). The remaining almost 17% are multi-family houses. At the end of 2021, there were a total of 43,084,056 housing units in residential and non-residential buildings. On average, dwelling units in single- and two-family houses are about 119 m² and in multi-family houses 70 m² (Destatis 2022a). There are roughly two million heated non-residential buildings in Germany.

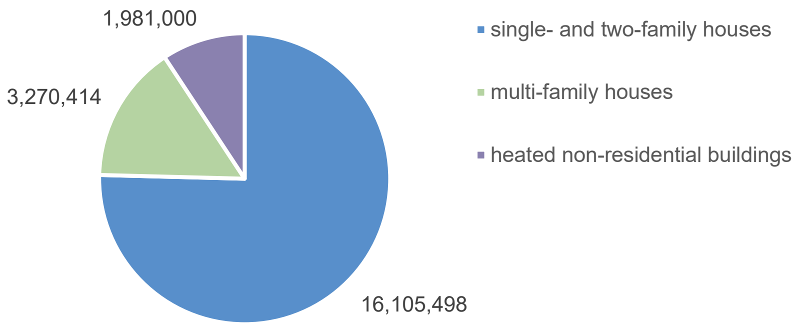

Figure 2-2: Building stock in Germany 2021

(Source: Destatis 2022)

2.1.2 Japan

Of the 7,735 million m^2 of total building floor area in Japan, residential buildings account for 5,749 million m^2 compared to 1,987 million m^2 of non-residential buildings. About four thirds (72.7%) of residential buildings are detached or row-houses, and about 60% are owner-occupied. About 33% (646 m m^2) of non-residential buildings are owned by the public sector (national or local government), mostly administrative office buildings, schools, daycare centers, and other care facilities.

Japan's population was 126.75 million as of 2018, with an average floor space per capita of 45.4 m^2/person out of the total residential area. The growth rate of the population turned negative for the first time in 2005 and has remained negative ever since, while the number of constructions starts has been steadily increasing.

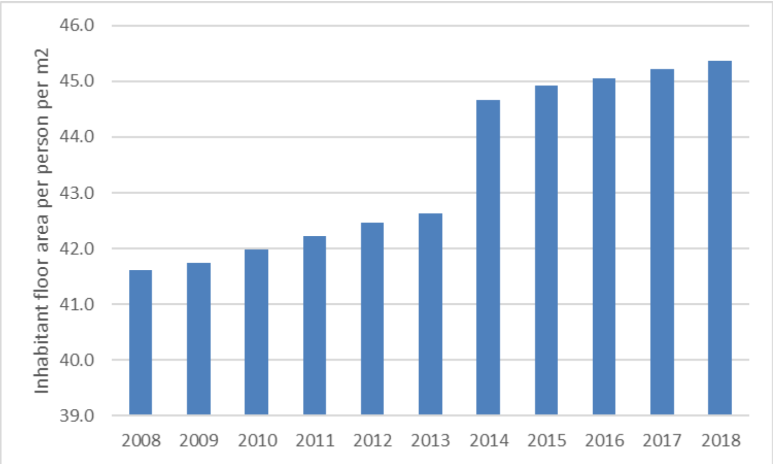

Figure 2-3: Inhabited floor area per person in Japan

(Source: estimate of the population and Building Stock, Statistics, e-Stat)

2.2 Average age of building stocks, and structure of buildings' age distribution

2.2.1 Germany

Around two thirds of the existing building stock in Germany was built before 1979. Compared to new buildings, the energy demand in existing buildings is on average up to five times higher.

2.2.1.1 Residential Buildings

Figure 2-4 shows that for residential buildings respective dwellings, around two-thirds were built before 1979, and almost half during the reconstruction after the damages of World War II.

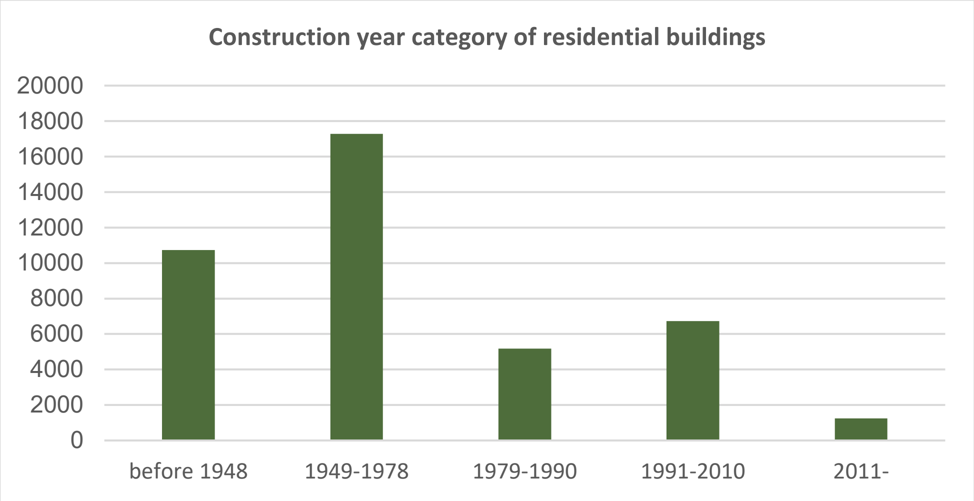

Figure 2-4: Source: Destatis 2022

Since 1995, and particularly between 1999 and 2009, the annual number of new residential buildings in Germany declined, before rising again after 2011. Currently, approximately 110,000 new residential buildings are constructed each year, with a noteworthy decrease by 9% in 2021 (Dena 2022).

Parallel to the declining number of new residential buildings, the number of demolitions has decreased, but remains at very low levels below 10,000/year (Destatis 2022).

2.2.1.2 Non-residential Buildings

Similar to the developments in the group of residential buildings, the constructions of new build has decreased considerably after 1979. The Institute for living and environment (*German*: Institut für Wohnen und Umwelt, *abbrev*.: IWU) categorized the construction age class in three types: (a) old building (before 1978), (b) "Zwischenbau" (1979-2009) and (c) new build (after 2010).

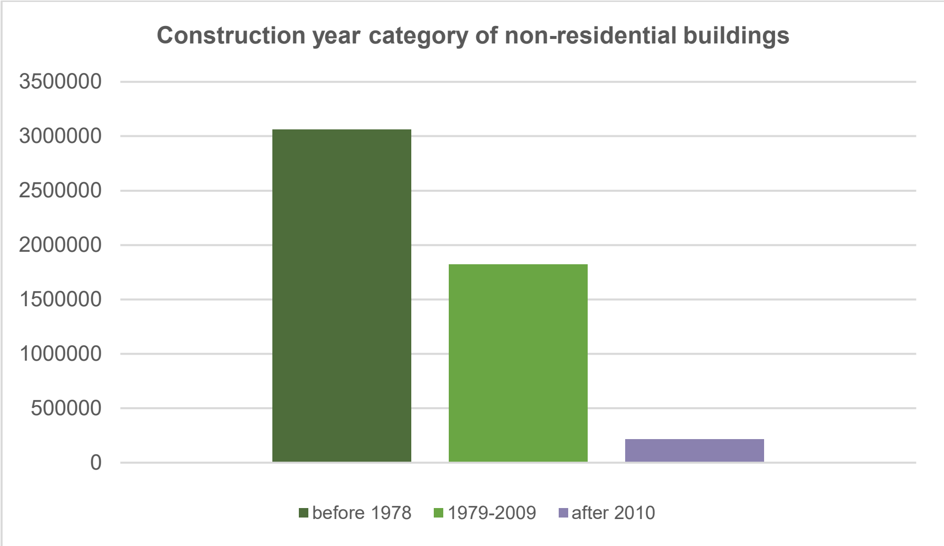

Figure 2-5: Building stock of non-residential buildings according to construction age class

(Source: IWU 2022)

2.2.2 Japan

Figures 2-6 and 2-7 show a comparative age distribution of existing buildings up to the year 2018. Most residential and commercial buildings are constructed from the year 1971 to 1990. In Japan, there has been a serious shortage of buildings since World War II. Thus, for the last six decades, construction activities in Japan have mainly focused on new building activities. A lot of houses built in Japan in the 1950s-1970s were built cheaply and quickly to cater to a booming population. At that time, the quality of buildings was not as important as it is today, and the standards were very different from those of today.

In earthquake-prone Japan, earthquake resistance standards have been strengthened after each major earthquake, and in 1981, based on the 1978 Miyagi Prefecture Off-shore Earthquake, the earthquake resistance standards were fundamentally revised. However, approximately 10 million houses built before 1980 do not meet the new standards. In addition, about 90% of the houses in Japan do not meet the current energy conservation standards because the energy conservation standards for houses established in 1980 were recommended standards, not mandatory standards.

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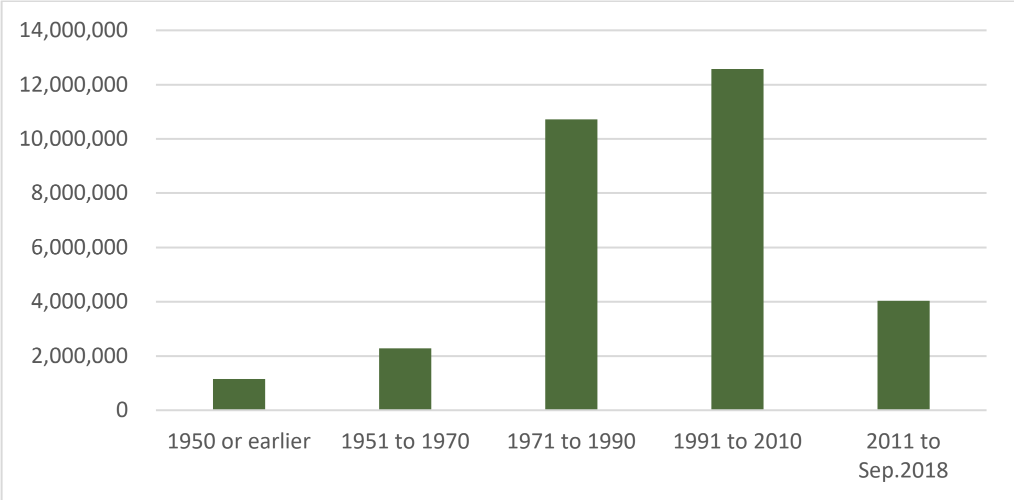


Figure 2-6: Residential Building by Year of Construction as of 2018

(Source: Ministry of Land, Infrastructure, Transport and Tourism (2022)).

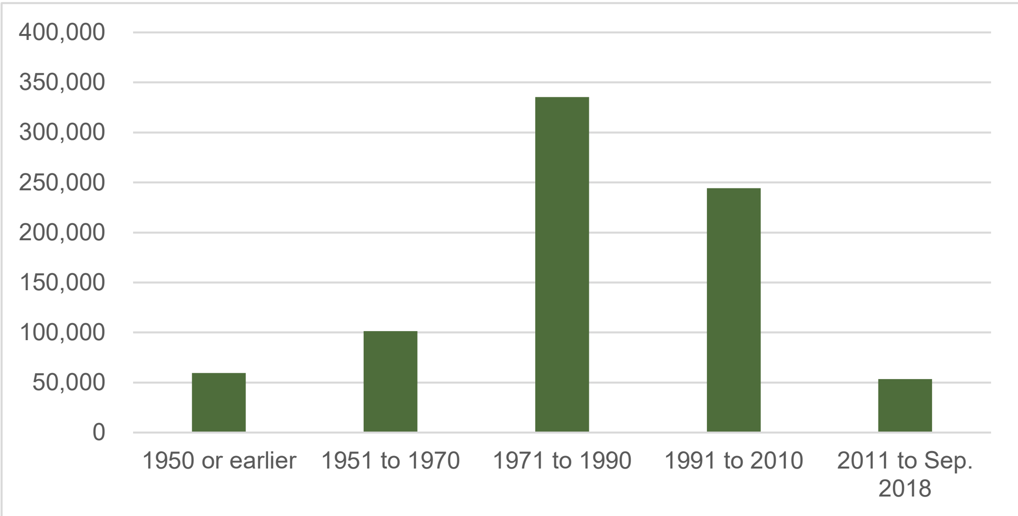


Figure 2-7: Commercial Building by Year of Construction as of 2018

(Source: Ministry of Land, Infrastructure, Transport and Tourism (2022)).

2.3 Energetic characterization of building stocks

Given differences in the geographical characteristics (climate, likelihood of earthquakes, humidity) of Japan and Germany the (energetic) characterizations of the buildings in both countries also differ considerably with regard to the construction material, the insulation level. These particularities are also partly reflected in different cultural habits, such as the usage of floor heating and practice of a hot bath.

2.3.1 Germany

Around one third of the existing building stock in Germany was built before 1979 and thus before the first *Heat Insulation Ordinance* came into force. Many of these old buildings have not been fully renovated in terms of energy efficiency or have hardly been renovated at all, while new buildings today have to meet high energy standards. Compared to new buildings, the energy demand in existing buildings is on average up to five times higher.

Brick, followed by other masonry units, is the predominant building material used in residential buildings built between 2000 and 2002. Until 2011, other masonry units also included sand-lime bricks. From 2003, with the exception of 2010, other masonry blocks were predominantly used. Since 2011, other masonry units have been subdivided in the statistics, so that bricks are the predominantly used building material for residential buildings, with a share of around 34% in 2011 and just under 30% in 2021. The share of construction completions of wood-framed residential buildings has increased from about 12% in 2000 to nearly 15% in 2010 and most recently to about 19 % in 2021.

The building materials predominantly used in non-residential buildings in construction completions from 2000 to 2021 were reinforced concrete, followed by steel. Other masonry units, wood, and miscellaneous building materials were used over the years with minor differences in the shares of total building materials. From 2010-2021, the share of reinforced concrete in the building material use has increased with fluctuations. The total annual volume of about 40,000 construction completions of non-residential buildings in 2000, decreased to about 27,000 in 2010, and was only about 22,000 in 2021. In contrast, the share of wood construction of non-residential buildings increased from about 12% in 2000 to about 20% in 2010 and 2021 (Destatis 2022b).

Commitments for new construction of *efficiency houses* or to renovate to efficiency house standards have increased enormously since 2018. *Efficiency houses* are buildings with particularly energy-efficient construction and building technology, with a better overall energy performance than required by law. The energy performance of buildings is measured in terms of transmission heat loss and annual primary energy demand. In new construction, *efficiency house commitments* in 2018 were still just over 30,000; in 2021, they were already close to 150,000. Applications for renovation into *efficiency houses* have risen from around 12,000 in 2018 to 23,000 in 2020, due to adjustments in subsidy rates (dena 2022).

From 2010 to 2016, the energy refurbishment rate in Germany was around one percent per year. The highest energy consumption is recorded in existing buildings built up to 1978. The overall refurbishment rate of old buildings built up to 1978 in Germany was 1.4% in 2010-2016 (IWU 2018).

According to an estimate by the German Energy Agency (dena), around 36% of Germany's existing buildings were retrofitted with insulation.[1] Due to subsidies for the Eastern German states after German reunification, the total share of energy renovation in Eastern Germany is about 16 to 22% higher than in the west. Roofs or top floor ceilings are the most frequently retrofitted building components, followed by exterior walls and basement ceilings or floors (dena 2019).

While single-glazed windows dominated in existing buildings from 1950 to 1978, uncoated insulated windows were increasingly installed from 1970 onward. Since the mid-1990s, these have been replaced by coated 2-pane thermal insulation glass with typical U_w-values of 1.3

[1] The estimates are based on the building stock data from the Institute for Living and Environment GmbH (*German*: Institut Wohnen und Umwelt, IWU) in 2018.

W/m²K. Triple thermal insulation glass (U_w below 1.0 W/m²K) has been on the market in Germany since 2005 (VFF / BF 2017).

According to a study by the Federal Association of Energy and Water Industries (*German*: Bundesverband der Energie- und Wasserwirtschaft; BDEW), of the 18.9 million residential buildings in Germany, 81.8% were equipped with central heating systems in 2019. About half of these, 40.5%, are natural gas-fired, 29.8% oil-fired, and 2.8% wood or pellet-fired. 3.4% of central heating systems are supplied by electric heat pumps, 5.4% are LPG/coal central heating, gas heat pumps, and other central heating systems. Only 5.4% of all residential buildings are heated with natural gas floor heating systems, 6.6% have district heating, and 6,2% have individual heating systems such as (night) electric storage heaters, wood/pellet individual heaters, gas individual heaters, coal individual heaters, and other individual heating systems (BDEW 2019).

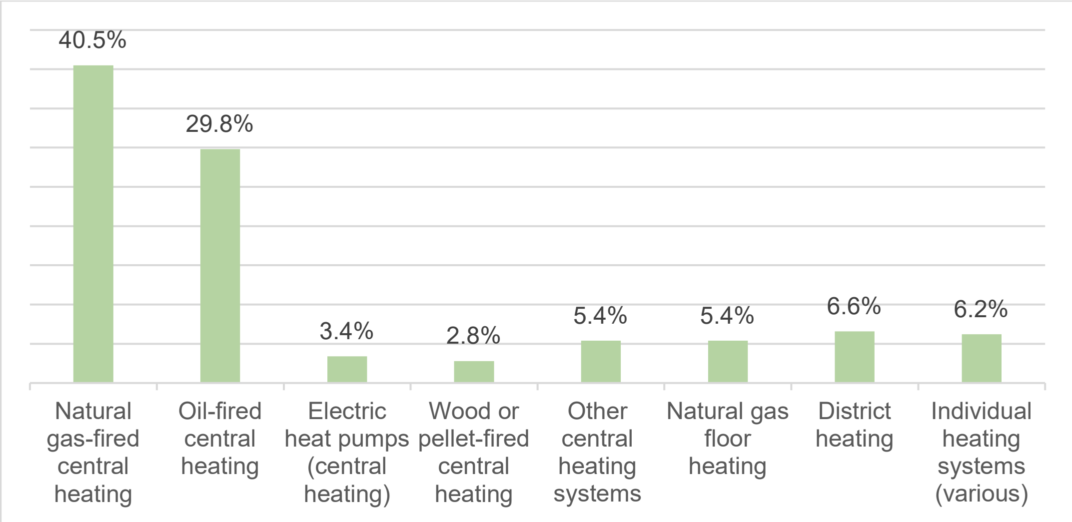


Figure 2-8: Germany: Heating systems in residential buildings 2019

Of the approximately 215,839 residential building completions in 2020 and 2021, about 89% of the buildings were equipped with central heating, 8% are supplied with district heating, and only about 2% were built with block heating. The share of installed floor heating systems and individual room heating systems was far below one percent in this period. 194 buildings were constructed without heating (Destatis 2022c).

2.3.2 Japan

The traditional Japanese building method is the wooden structure. Starting from the 19th century, construction methods other than wooden construction methods were promoted for larger buildings, because wooden buildings were considered vulnerable to fires and inferior in terms of durability. According to the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), the average lifespan of a wooden house is 27-30 years, while for reinforced-concrete apartment buildings, it is around 37 years.

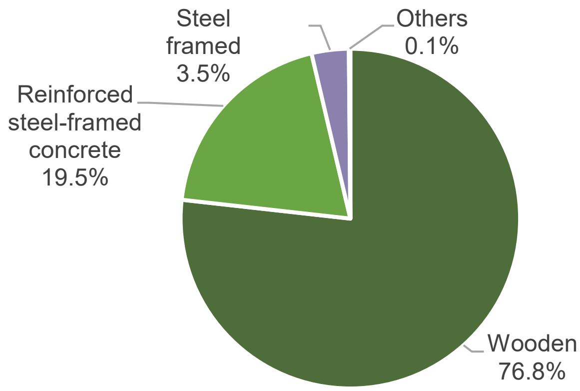


Figure 2-9: Structure type of residential building (FY2018)

2.3.2.1 Residential buildings

The Japanese government aims to increase residential and residential building's energy efficiency standard to achieve zero energy buildings (ZEHs) in newly constructed ones by 2030 and achieve stock average of residential and commercial buildings to achieve ZEH level by 2050. A Net Zero Energy House (ZEH) is a house with an annual net energy consumption around zero (or less) by saving as much energy as possible and using renewable energies while maintaining a comfortable living environment. This can be achieved through better heat insulation, high-efficiency appliance/equipment, and creating energy with photovoltaic power generation.

A large majority of 90% of the existing housing stock does not meet current energy efficiency standards. By 2050, it is expected that a considerable number of houses will be rebuilt to meet energy-saving standards. However, not all houses will be rebuilt and there will be leftovers of old houses. Thus, in order to reduce the current residential energy consumption as soon as possible, it is essential to promote insulation and energy-saving retrofitting of existing homes. Housing business operators use government subsidies, such as for housing thermal insulation renovation support projects using high-performance building materials to renovate the entire house or partial insulation and energy-saving renovations.

Heating and cooling account for approximately 30% of the household energy consumption in Japan. An energy-efficient home uses less energy for heating and cooling. In winter, the warm air in the room does not escape, and in summer, heat from the outside does not enter the room, so you can have a comfortable time with less energy for heating and cooling. In other words, it can be said that an energy-efficient home equals comfort and well-being in housing. To realize an energy-efficient home, the three pillars of an energy-efficient home are heat insulation, solar radiation shielding, and air tightness.

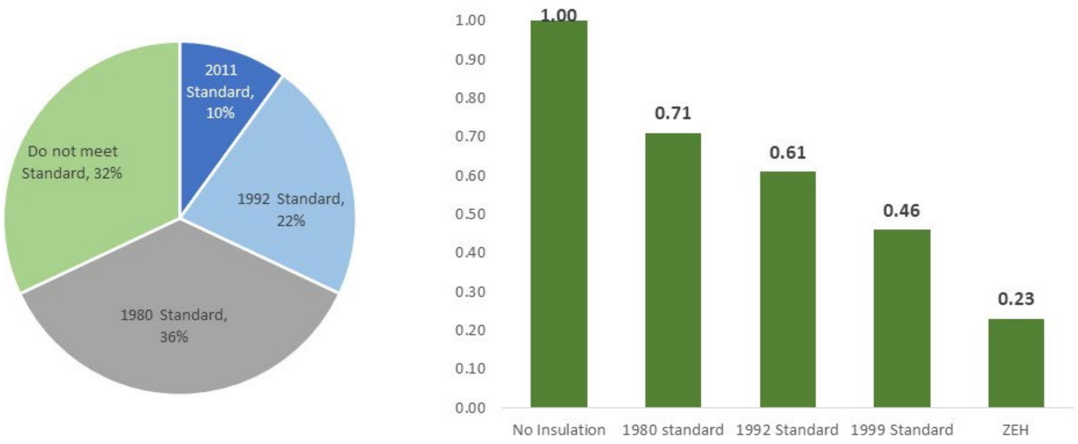


Figure 2-10: (Left)Thermal Insulation performance of about 50 million housing stock (FY2017) (Right) Housing Insulation Performance

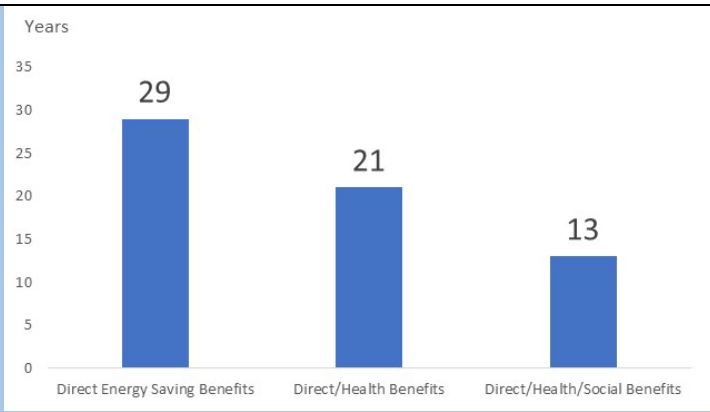
Health Benefits of Thermal Insulation: Case in Japan

High thermal insulation of residential buildings can yield such benefits as energy-savings. Meanwhile, it is important to note the secondary benefit such as the effect on health or wellbeing. In Japan, annually about 19,000 people died from heat shock caused by the difference in temperature between the living room and the dressing room in the bath, which is in contrast to the number of people died in traffic accidents at 2,610 in 2022. A study by Ikaga et al., presents the results of a questionnaire regarding how people's health conditions improve by moving to highly insulated and highly airtight housing. Specifically, the improvement rates are: for cerebrovascular disease (84%), heart disease (81%), diabetes (71%), bronchial asthma (70%), and arthritis (68%).

The effect of improving health condition through insulation is expected to reduce the burden of medical expenses on household expenses. The secondary effect of reducing the burden of medical expenses on the national government is significant as well. In the research by Ikaga et al., the secondary benefit of insulation per household is estimated to be 27,000 yen per year which covers both the avoided burden of medical expenses and the prevention of loss from work. On the other hand, according to the results of the above-mentioned questionnaire, the total benefit per household is estimated at 12,000 yen per year for the avoided medical expenses for heart disease and cerebrovascular disease, which have the highest rate of improvement due to relocation, reduction, and prevention of lost work time.

With reference to this, assuming the investment requirements for thermal insulation at one million Yen, energy savings only can take 29 years to recover the cost. Meanwhile, health benefits combined with energy saving benefits can improve the cost recovery to 21 years. By considering the direct benefits of high insulation, the reduction of medical expenses for households, the prevention of loss of work lost, and the effect of reducing social medical expenses, it will be reduced to 13 years.

Box: The number of years required for cost recovery from thermal insulation



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2.3.2.2 Non-residential sector

The Japanese government aims to increase residential and commercial building's energy efficiency standard to achieve zero energy buildings (ZEBs) in newly constructed ones by 2030 and achieve stock average of residential and commercial buildings to achieve ZEB level by 2050. A ZEB is a building with considerably reduced annual energy consumption by saving as much energy as possible via better heat insulation solar radiation shielding, natural energy and high-efficiency equipment as well as creating energy (e.g., with photovoltaic power generation), while maintaining comfortable environments. To achieve ZEBs, the government of Japan has also decided to introduce obligation for newly constructed buildings and houses to meet the energy efficiency standards by 2020. The obligation to meet the standards has started to be phased in for large-scale non-residential buildings based on the Building Energy Efficiency Law established in 2015. The act expanded the mandatory sector to medium-scale non-residential buildings in 2021 and the all sectors including residential housing will be covered in 2025.

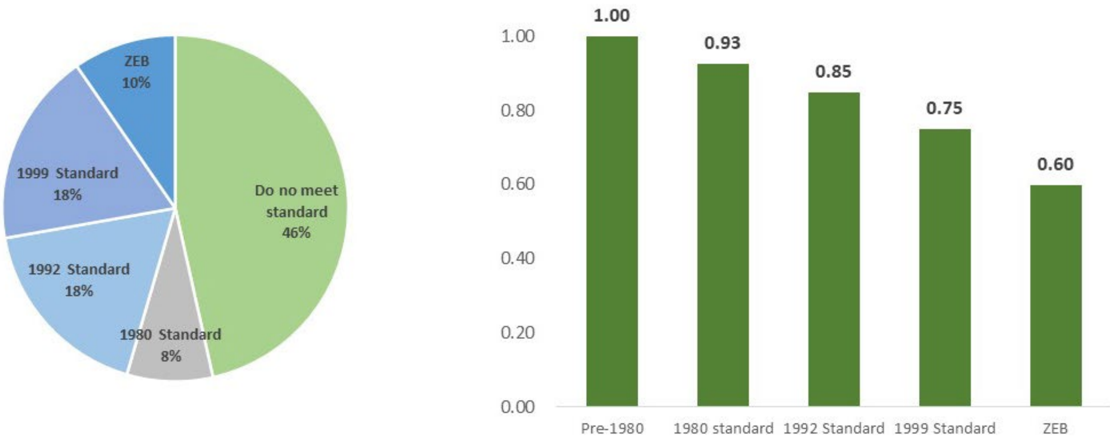


Figure 2-11: (Left)Thermal Insulation performance of commercial building stock (FY2017) (Right) Commercial Building Insulation Performance

Similar to the residential building stock, the majority of existing commercial building stock does not meet current energy efficiency standards.

2.4 Buildings‘ energy intensity

Due to a number of measures aiming at better insulation of buildings as well as increasing the overall efficiency of heating, cooling, and other electric and electronic appliances used in buildings, the energy intensity of buildings has been gradually reduced throughout the years in both countries.

2.4.1 Germany

While Germany’s overall per capita floor area has increased, there has been a reduction of the energy intensity: The calculated energy intensity for 2020 for residential buildings amounts to 156.4 kWh/m^{2}a as compared to 204.9 kWh/m^{2}a in 2010, based on not-weather-adjusted data (BMWK 2022). This can be related to improvements in the building insulation as well as in energy efficiency of heating systems. While it is almost a 20% improvement, it is far not harnessing the potentials yet (cf. Rauschen et al., 2020), and far too little for a cost-effective decarbonization of the building stock.

Due to the predominantly central heating systems in Germany and the heating-dominated climate (3,500 to 4,000 heating degree days, 10 to 50 cooling degree days incl. zero dehumidification needs), a large share of the overall energy used in buildings is accounting for heating. Notably, the energy used for cooling in residential buildings has first been measured in 2013, with considerably low values at 0.33 kWh/ m^{2}a.

A new assessment of the floor area that non-residential buildings account for has only recently been published again, which makes it difficult to show the development of the energy intensity of non-residential buildings throughout the years. Taking the energy data from the year 2020 and the floor area from 2021, the overall energy intensity for non-residential buildings of the year 2020 can be said to be approximately 136.2 kWh/m^2/2020 (BMWK 2022).[2]

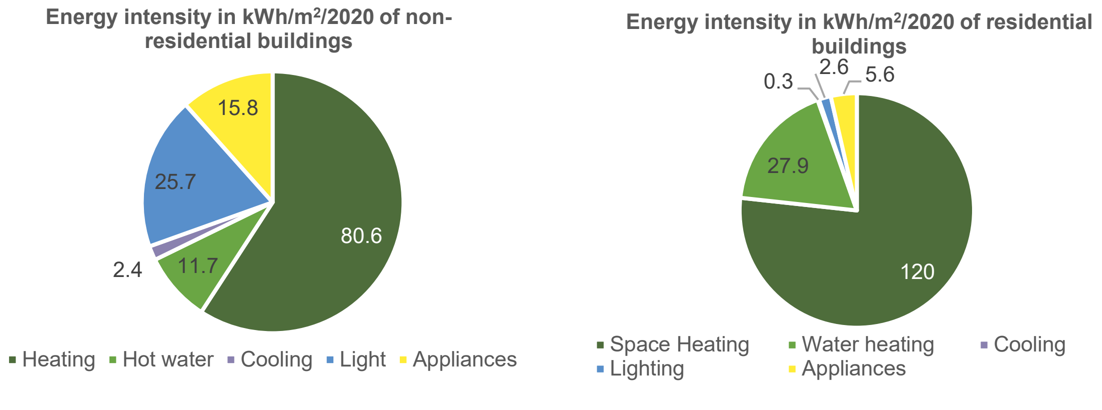


Figure 2-12: Source: BMWK Energy data (2022)

Again, heating accounts for the largest share of the thermal energy used in the buildings, amounting to 85%.

[2] Please note that the data for the floor area taken into account has been taken from the year 2021.

2.4.2 Japan

In the residential sector, energy intensity in this section is defined as the energy consumption per household. Based on Fig.2-13, it can be observed that Japan’s residential energy intensity has increased up to 1995, then improved with a strong decoupling from its economic development. From 1980 to 2020, Japan’s GDP per capita increased by 77%, while its residential energy intensity improved by 3.8%.

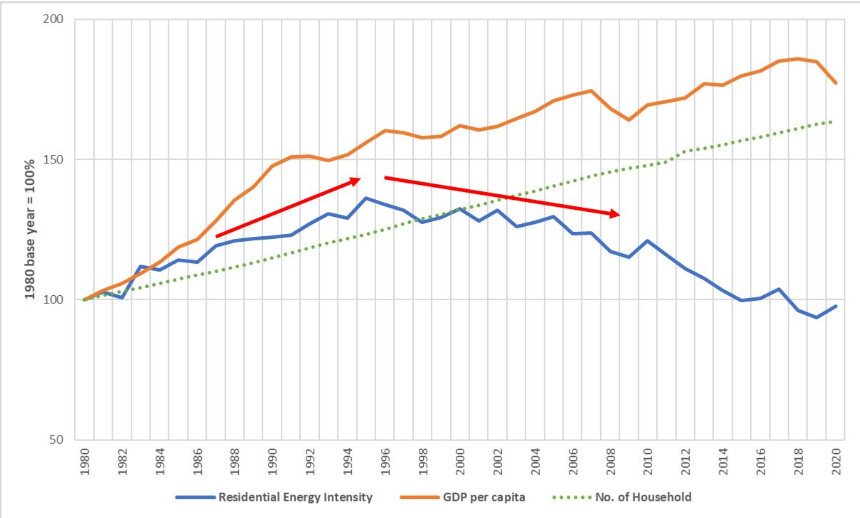


Figure 2-13 Trends in Residential Sector Energy Intensity, No. of Households, and GDP per capita

2.4.2.1 Non-residential sector

In the commercial sector, energy intensity in this section is defined as the energy consumption per unit of floor space. The trend toward the service economy in the commercial sector and increasing floor space have contributed to higher energy demand. From 1980 to 2020, Japan's GDP increased by 90%, while its commercial energy intensity improved by 29%.

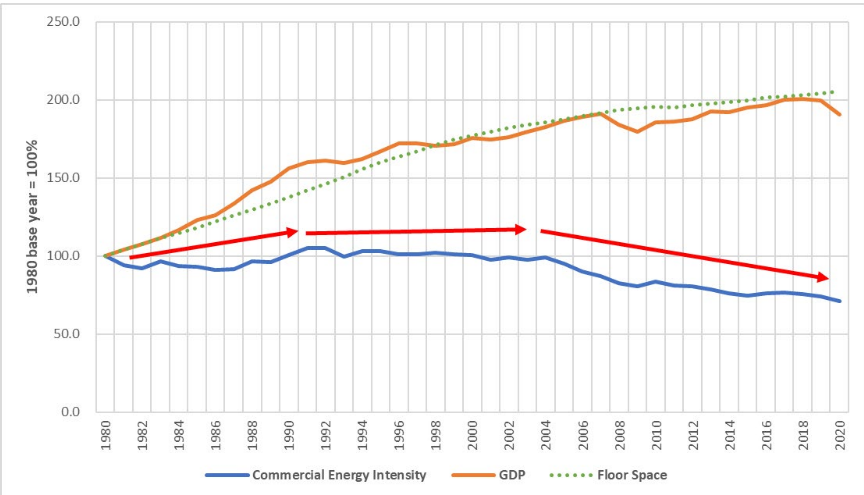


Figure 2-14 Trends in Commercial Sector Energy Intensity, Floor Space, and GDP

2.5 Buildings’ energy consumption by usage and by type of energy

Developments in both countries to improve the energy efficiency has contributed to overall reduction of the energy consumption in Germany and Japan. While the energy intensity has thus improved in both countries, the overall consumption of energy is still at a high level because of an increase in floor space and the increase of (bigger) electronic appliances. To reduce the overall energy consumption of buildings, the focus of Japan and Germany differs notably: While Germany pushes for the improvement of insulation, Japan focus lays on improving the energy efficiency of electronic appliances.

2.5.1 Germany: energy consumption by type of usage and type of energy

Following the introduction of higher standards (cf chapter 3) the overall energy consumption of buildings per sqm has been successfully reduced. However, due to an increase of per capita floor area, the energy consumption in the building sector remains high. In Germany, 36% of the total energy consumption in buildings are attributed to non-residential buildings (dena 2022).

Figure 2-15 shows the final energy consumption for residential and non-residential buildings over a time period of 25 years (1996-2021) sorted by usage (dena 2022). The total energy consumption amounts to 907 TWh in 2021, while a great share of 817 TWh accounts for space heating and hot water, of which 69% was used by private households. In comparison, only a small share of 25% was used by the tertiary sector and 6% by the industry. While the total energy consumption did not reduce further since 2014, the share of air conditioning has risen from 1% in 2018 to 3% in 2021. The installation of air conditioning is increasingly coming into practice in Germany. Other appliances are not included in these data.

In Germany, the energy amount used for space heating decreased between 1996-2014 from 658 TWh - 408 TWh and increased again to 459 TWh until 2021. The final energy consumption for hot water has also increased from 92 to 106 TWh in 2021. Despite the effort to reduce final energy consumption, no significant savings could be achieved in recent years. The reason for this is the growth in population and floor area, which compensated for the reduction in energy intensity especially since 2014.

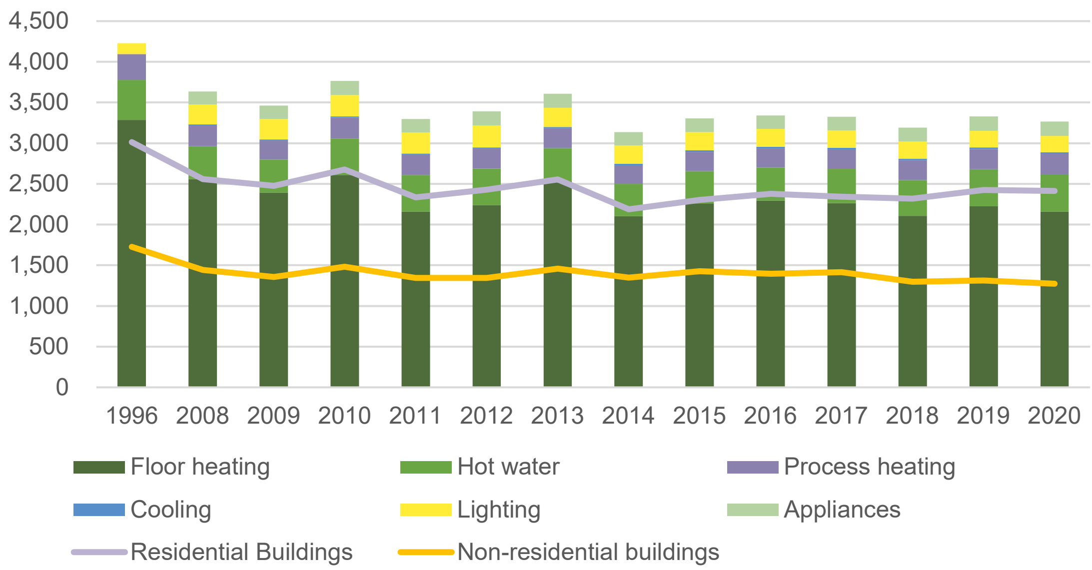


Figure 2-15: Energy consumption by usage in (non-)residential buildings in Germany

Source: BMWK Energy Data 2022

Figure 2-16 illustrates how the type of energy source/final energy evolved since 2010. The greatest share still contains oil and gas, which constantly remain by about 75%, although the oil demand decreased by about 4%. Gas takes the largest share for hot water with 58%, followed by electricity with 14% and oil with 13%. The picture is similar for space heating in residential buildings. Here, gas also accounts for the largest share (48%), but here followed by renewables (21%, mainly wood) and oil (17%).

District heating decreased from 16% to 5%. The share of renewable energies increased from 3% to 15% for heating and hot water since 2008. However, the share of renewables only gradually increased since 2017.

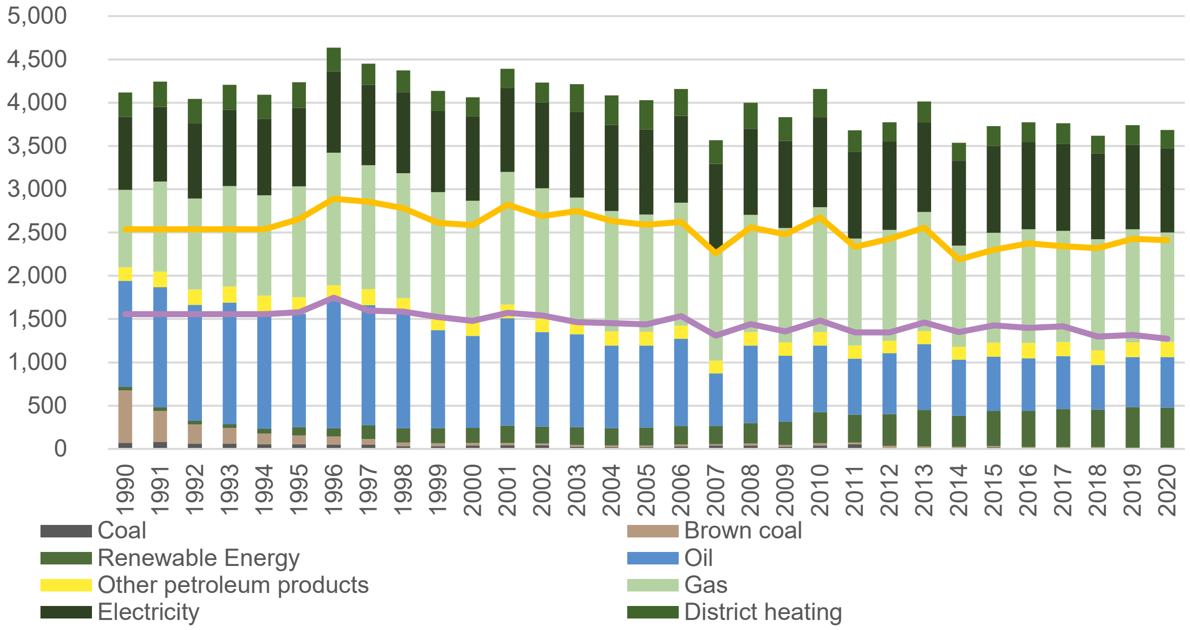


Figure 2-16: Energy consumption by type of energy (in PJ)

Source: BMWK Energy data, 2022

Electronic appliances for various purposes are on the rise in Germany. Among the most populated ones are televisions, followed by DVD players and dishwashers: More than 96% of all Germans have at least one TV at home (2000-2022). A considerable high percentage also possessed a dishwasher in 2022 (74.6% as compared to 48.3% in 2000) or a Personal Computer (92% in 2022 as compared to only 47.3% in 2000). While the overall distribution of DVD players has increased throughout the early millennium years (14.1% in 2002 compared to 70.8% in 2010), they seem to have been replaced recently by Blue-Ray-only-Players amounting to 24.8% in 2022. Other important electronic appliances concern tumble dryers (31.8% in 2000 and 42.7% in 2022) as well as dishwashers (48.3% in 2000 and 74.6% in 2022). Such an increase in numbers of electronic appliances contributes to the overall energy consumption of households.

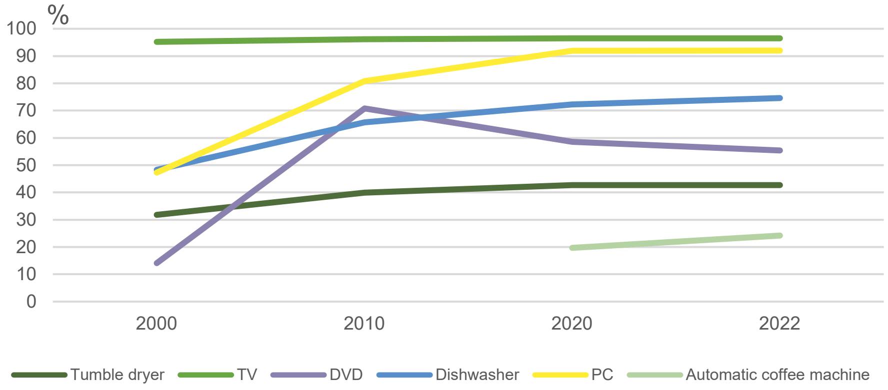


Figure 2-17: Electronic appliances in Germany (2000-2022

Source. Statista 2023

2.5.2 Japan: Energy Consumption by usage and by source

In the residential and commercial sector, energy is utilized for various purposes like heating, cooling, kitchen utilities, hot water, lighting/appliances. Energy consumption by lighting/ appliances continues to grow, driven mainly by increasing numbers of buildings and ownership of appliances and digital gadgets.

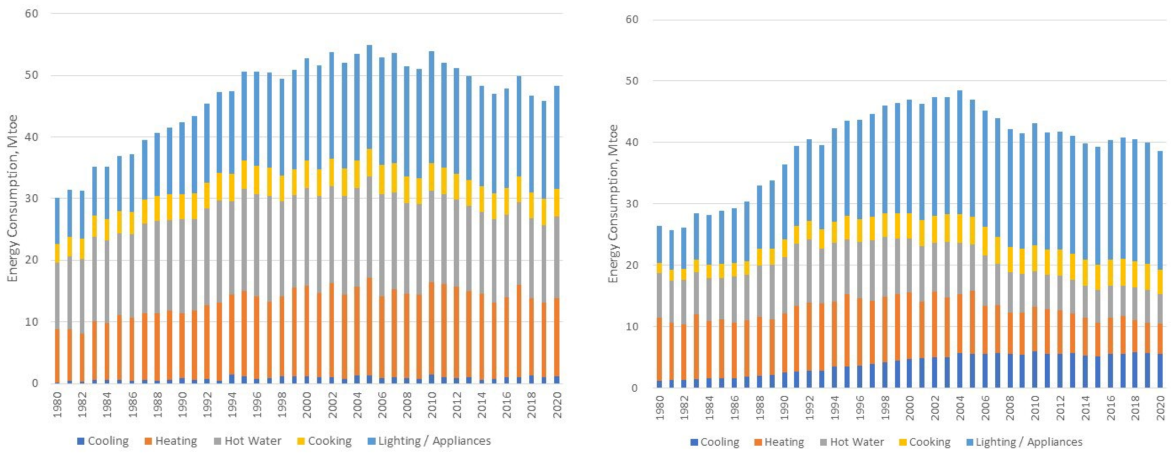


Fig. 2-1: Comparison of energy consumption by usage in residential (left) and non-residential buildings (right)

Figure 2-18 shows that energy consumption and end-uses in Japanese households differ significantly from other developed nations. Japan's energy consumption for "heating" is particularly low, while the consumption of "hot water" is higher. It is mainly due to the differences in heating methods and different climates. While people in other countries heat/cool their homes using central controlled system, most Japanese housings are using "intermittent heating/cooling." Japanese people heat/cool their homes only at the place and time they require heating/cooling. In addition, the Japanese practice hot water bath, which results in higher energy consumption in "hot water" compared to other nations.

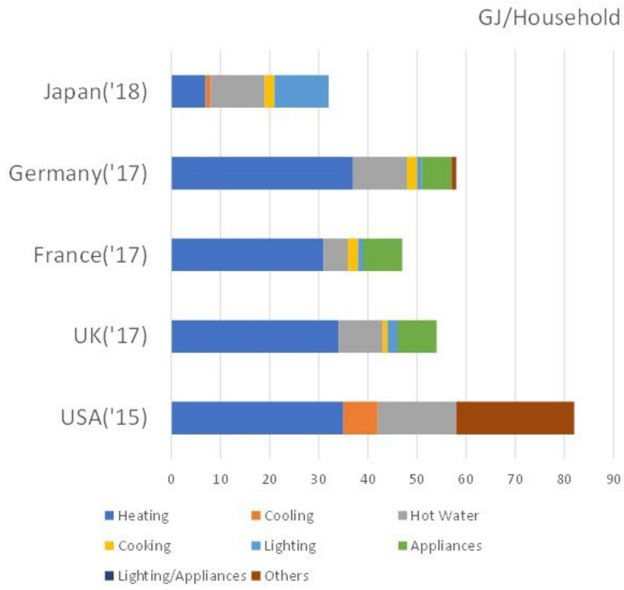
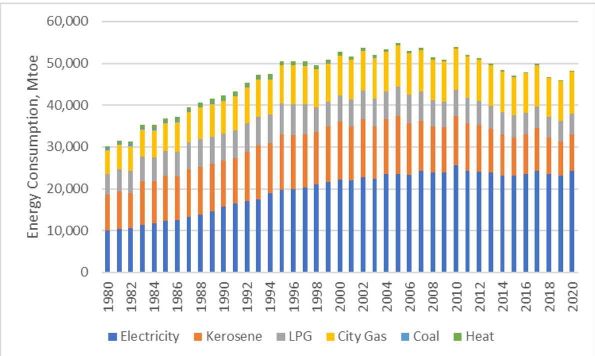


Figure 2-18: Comparison of residential energy consumption by country

The socioeconomic development has raised living standards and directly contributed to the overall increase in residential and commercial buildings' energy consumption. Below figures show the historical trends in the energy consumption of residential and commercial sectors by type and usage

Figures 2-19 show the historical trend of residential and commercial energy consumption by type. Electricity consumption has increased significantly due to the increase ownership of electric appliances, and shifts from oil and coal. From 1980 to 2020, residential electricity consumption increased by 18%, while commercial electricity consumption increased by 34%.



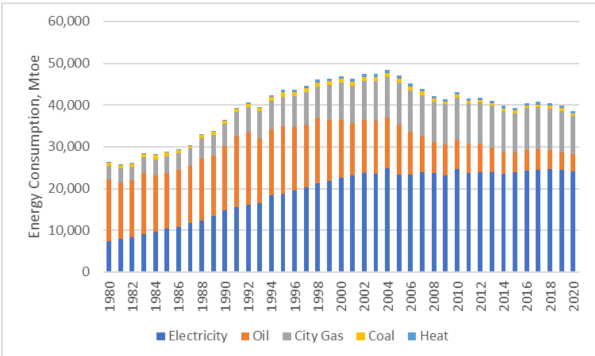


Figure 2-19: Comparison of residential energy consumption in residential (left) and non-residential (right) buildings by type of energy

(Source: EDMC Statistics (2022).

Table 2-1: Ownership rate of appliances (units/100 households)

	1980	1990	2000	2010	2020
AC	57.9	126.5	217.4	259.9	282.7
TV	150.9	201.3	230.6	239.6	207.6
DVD	-	-	-	133.1	122.5
Computer	-	12.7	65.8	122.9	128.3
Washlet	-	-	53	95.9	113.2

The socioeconomic development has led to a widespread diffusion of electrical appliances and increased electricity consumption. The average ownership rate of household appliances has been growing steadily from 1980 to 2020. Nevertheless, as a result of rising electricity prices observed from 2011, people are shifting towards more energy-efficient appliances, albeit at relatively higher costs.

3 Policies and Strategies towards Decarbonization

3.1 Overview of major existing policies

3.1.1 Germany and the European Union

In 1979, the first *Heat Insulation Ordinance* was introduced, setting new energy efficiency standards for German buildings. Often, the policies in Germany are required and guided by EU directives (cf textbox "EU regulations and its impact on Germany's policies" at the end of this chapter). In addition to regulations described in 3.1.1.1 that are imposed on building owners, there is also a number of information and advice programs as well as financial incentives/financing mechanisms to support them in implementing energy efficiency measures, such as energy renovation and exchange of heating systems (cf 3.1.1.2).

Among the major existing policies aiming at improving the building sectors' energy efficiency are the following:

1) Energy performance and renewable energy requirements, and the Buildings Energy Act (Gebäudeenergiegesetz, GEG)
2) Energy performance certificates and energy advice programs
3) Financial incentives and financing schemes

In addition to specific energy efficiency policies for buildings, there is also the German Climate Protection Law that sets sector targets, including for the building sector (cf. chapter 3.2). Following the revision of the German Climate Protection Law in 2021, the sector targets have been tightened, now aiming at a reduction of annual emissions by 53 Mt CO_2 (44%) until 2030 in the building sector. So far, however, little progress has been made. Generally, the GHG emissions gradually decreased since 1990 with a sharp decline in 2020 due to the pandemic (cf. fig. 3-1). However, particularly the transport and the building sector missed their targets for 2020 and 2021. Accordingly, substantial additional measures are necessary to eventually meet the targets in 2030, cf. chapter 3.2.

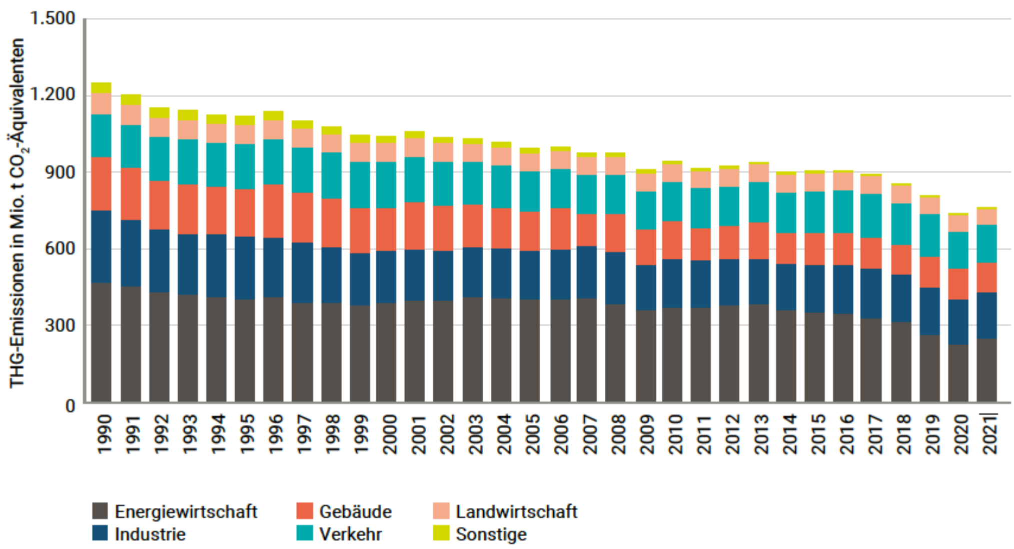


Figure 3-1: Sector specific development of GHG emissions in Germany (UBA 2022a)

3.1.1.1 Buildings Energy Act (GEG)

The *Buildings Energy Act* (GEG) was introduced on 01.11.2020. It is a combination of the *Energy Saving Act* (EnEG, 1976-2020), *Energy Saving Ordinance* (EnEV, 2002-2020) and *Renewable Energies Heat Act* (EEWärmeG, 2009-2020) into a uniform set of regulations. Compliance with it is mandatory for new buildings and in case of major renovation, [3] when energy-efficient renovations are required. The GEG is the legal basis for the energy assessment of residential and non-residential buildings. It represents a uniform system of requirements in which thermal insulation and the overall performance of the building envelope, energy efficiency of the installed systems, and renewable energies are integrated.

Buildings Energy Act (GEG): Energy performance requirements

The German law distinguishes between requirements for new buildings and renovations as well as between residential and non-residential buildings:

- For new buildings, requirements are set for the annual primary energy demand of the building, the energy quality of the building envelope and the use of renewable energies. When defining the primary energy factors of energy sources, the energy demand for extraction, processing and transport of the energy sources is considered by means of lump-sum primary energy factors.
- Residential buildings' energy requirements are set for heating, domestic hot water, ventilation, and cooling. Non-residential buildings also have energy requirements for the same end uses plus lighting.
- The maximum allowed value for the annual primary energy demand of a new building is determined individually for each building, based on a reference building with the same shape and size.
- According to current legislation, the annual primary energy demand of new planned buildings with the planned thermal insulation and technical equipment must currently be at least 25 % below the annual primary energy demand of the reference building.

Figure 3-2 presents an example of the development over time of the requirements for new residential buildings (step curve), following advances in research and development (lower curve).

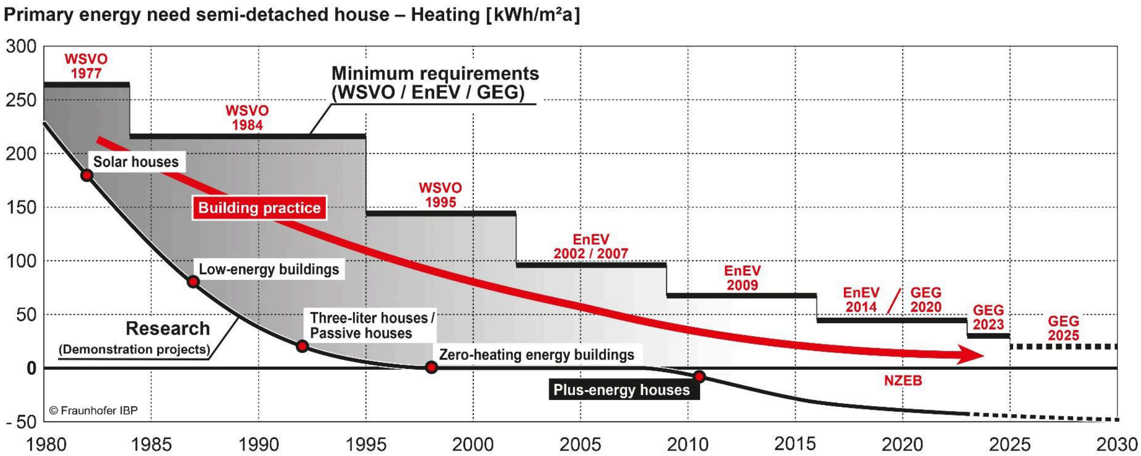


Figure 3-2: Evolvement of energy performance requirement for new residential building

(Source: Hans Erhorn, Head of Department of Energy Efficiency and Indoor Climate, Fraunhofer IBP) 2022

[3] Major renovation is defined as 'more than 25% of the surface of the building envelope undergoing renovation' (for whichever reasons).

3.1.1.2 Energy performance certificates

A building that is sold or rented must have an *Energy Performance Certificate* (EPC) according to the building energy act. The final and primary energy demand are shown in the EPC. Calculation is based on *DIN 18599 Energy Performance of Buildings*. For residential buildings, there is an energy classification on an A+ to H scale (cf. Appendix).

- It must be presented to interested parties at the latest when viewing the property.
- After conclusion of a purchase, lease, or rental agreement, it must be handed over.
- It is also an orientation for the energetic building renovation and shows energetic deficiencies of the building as well as possible measures to improve the energy performance.

3.1.1.3 Energy advice system and financial incentives for energy consulting for residential buildings

The current directive on the promotion of energy consulting for residential buildings came into force on 01.02.2020. Comprehensive energy consulting for residential buildings is eligible for grants, in case of the German form of a *renovation passport* with 80% of the cost. This type of an energy refurbishment concept must show to the building owner how a residential building can be comprehensively refurbished for energy efficiency step by step over a longer period or how, with the help of the comprehensive refurbishment, an *efficiency house standard* can be achieved that can be funded by the federal government.

3.1.1.4 Financial incentives for energy-efficient renovation and renewable heating systems

The funding for financial incentives and soft loans for the energy efficiency of buildings and the use of renewable heat is provided since ca. 2005. The last major revision of the programs was on 01.07.2021. It is now named *federal funding for efficient buildings* (BEG). The total amount of government spending for these programs used to be around € 2 billion per year and was increased to around € 5 billion/year in 2021/22 as a countermeasure against the recession caused by Covid-19. The BEG contains three subprograms: (1) residential buildings (systemic), (2) non-residential buildings (systemic) and (3) individual measures.

Financial support is offered for systemic measures, with which a specified efficiency level of the entire building is achieved during the renovation or new construction of buildings. The new or renovated building has to meet the requirements of a so-called *efficiency house standard*. The higher the *energy efficiency standard*, the higher is the grant, up to 20% in renovation. Grants are also offered for individual measures for the energy-efficient refurbishment of residential and non-residential buildings.

Applicants can choose between a loan with a reduced interest rate and a grant component or a direct investment grant. Prerequisite is a compliance with minimum technical requirements, and an approved energy efficiency expert must be involved, who accompanies the subsidized construction measures and certifies compliance with the subsidy requirements. Specific requirements for an efficient building are defined in terms of the annual primary energy demand, as a percentage of the demand of the reference building as defined in the GEG.

The use of renewable energies in residential as well as non-residential buildings is rewarded with a 5% higher grant and a € 30.000 higher maximum subsidy amount for each efficiency house class. To achieve this *renewable energy class*, at least 55% of the heating and energy requirements of the efficiency house must be covered by renewable energies or waste heat. Alternatively, the consideration of sustainability aspects in non-residential buildings is rewarded with the higher maximum subsidy amounts for each efficiency house class too. With sustainability certification, energy-efficient non-residential buildings can achieve the so-called *sustainability class* for the higher grant percentage limits.

3.1.1.5 Lifecycle Assessment and Embodied Energy (non-renewable primary energy) – Existing Policies

Requirements for CO_2 eq. kg/m² (GWP) and non-renewable primary energy MJ/m² (embodied Energy) and other environmental impacts, have existed in the German sustainability certification systems (DGNB (German Sustainable Building Council) and BNB (Assessment System for Sustainable Buildings) since 2008. A life cycle assessment (LCA) must be carried out for all buildings to be certified.

Since July 2021, the federal government has been promoting sustainability aspects through its own *NH-Klasse* (Nachhaltigkeitsklasse, *engl.* sustainability class) as part of the BEG. The required proof for the financial support is provided by awarding the building related QNG (Qualitätssiegel für Nachhaltige Gebäude, *engl*. Quality Seal Sustainable Building). The requirements for the QNG include the following (using residential buildings as an example):

- General requirement: the building must be certified according to an approved registered sustainability rating system.
- Specific requirements (selection): Compliance with defined requirements for greenhouse gas and non-renewable primary energy. Use of wood from sustainable forestry for at least 50% of wooden building parts.
- There are different requirements for residential and non-residential buildings.

Since about 2010, data and calculation tools are available free of charge for LCA calculations (cf. Appendix).

3.1.1.6 The EU Ecodesign Regulation

In 2005, the EU agreed on the Ecodesign Directive which aims at reducing the environmental impact of energy-related products by setting minimum requirements for the product design. Energy-related products refers to products that either do or do not directly need energy to be operated but partly influence the energy consumption (e.g., the amount of (hot) water running through a shower head). Importantly, the directive, that has been revised in 2012 and 2016, takes into account not only the energy used to operate the products but the entire life cycle of the products. The Energy-Related Products Act (EVPG) transposes the directive into German law.

In addition to self-regulatory initiatives by the industries, certain products are subject to strict regulation if:

- they reach an annual sales volume of 200,000 pieces and more
- they have a significant impact on the environment according to the defined priorities of the European Commission (cf. 1600/2002/EG)

- considerable potential to improve the environmental-friendliness without causing excessive costs

The current list of products subject to regulations comprises a number of 29 products, among them refrigerators, circulation pumps, dish washers, windows, insulation materials and light.

According to the estimation of the European Commission, the release of ten new Ecodesign regulations in 2019 will potentially lead to energy savings amounting to 167 TWh by 2030, which corresponds to roughly 46 million tons of CO_{2eq}. Based on this EU regulation, the industries' competitiveness is ensured while their costs for energy and resources are reduced.

EU regulations and its impact on Germany's policies

Since 2002, the EU has a framework directive on the overall *Energy Performance of Buildings* (EPBD, currently Directive 2018/844/EU). Together with the *Energy Efficiency Directive* (2012/27/EU), the EU thus established a legislative framework to boost the energy performance of buildings among the Member States, aiming at:

- a highly energy efficient and decarbonized building stock by 2050
- a stable environment for investment decisions
- the provision of information enabling consumers and business to make more informed choices to save energy and money

It has been revised twice since then, and it requires the EU Member States to implement certain types of policy instruments as listed below:

1. **long-term renovation strategies** aiming at the decarbonization of the national building stock by 2050 (with indicative milestones for 2030 and 2040) aligned with the national energy and climate plans (NECPs)
2. **minimum energy performance requirements** for new buildings for existing buildings undergoing major renovation, and for the replacement or retrofit of building elements like heating and cooling systems, roofs and walls
3. for all new buildings built after 2021 (for all new public buildings since 2019) the nearly zero-energy building (NZEB) standard applies that energy performance certificates – **energy performance certificates** must be issued upon sale and rental
4. **regular inspections** for heating and air conditioning systems are required
5. once exceeding a certain size, car parks must provide the necessary infrastructure for **electro-mobility**
6. enabling the installation of **smart technologies** (e.g., devices that regulate temperature at room level) that also address health and well-being of users
7. ensuring the improvement of energy efficiency of buildings by providing list of **national financial measures** (increasing transparency)
8. (based on the *Energy Efficiency Directive*) ensuring that at least 3% of the total floor area of public buildings undergo **energy efficient renovations**

It is, therefore, the EU framework for most of the national policy measures presented above.

3.1.2 Japan

3.1.2.1 History (from energy intensity)

The two oil crises in the 1970s triggered the establishment of “The Energy Conservation Law” (hereinafter referred to as EC Law) in 1979 to promote energy saving and energy conservation. Historically, EC law was enacted to improve energy efficiency in the industry sector. To cope with climate policies and rising energy consumption, the EC law was amended to include the residential and the commercial sectors. When the Kyoto Protocol came into force in 1998, Japan was required to accelerate further energy conservation efforts to achieve its GHG emission reduction target. In 1998 the Top Runner Program was introduced in the revision of the EC Law to save energy consumption in the residential and commercial sectors by setting ambitious efficiency targets for appliances. It is now considered one of the most significant climate policies of Japan, as the Top Runner Program covers 70% of appliances energy usages.

After the Great East Japan Earthquake in 2011, Japan faced an energy crisis in its electric power supply due to the nationwide shutdown of nuclear power plants. It was necessary for Japan to secure the effective utilization of fossil fuels and increase renewable energy to make up for the generation losses from nuclear power. On top of these supply-side-measures, it was necessary for Japan to improve the energy efficiency and conservation of residences, buildings, facilities, and equipment in the commercial and residential sectors. Against this background, the EC Law was revised to add measures relating to (1) the promotion of electricity demand leveling and (2) the expansion of the Top Runner Program to include further energy-consuming equipment.

1979	**Energy Conservation Law**	
	Envelope Standard	**Primary Energy Use Standard**
1980	Class 2 Standard	
1992	Class 3 Standard, Heat Loss(Q) and Solar Heat Gain (μ) Coefficient	
1999	Class 4 Standard, adding Air Tightness (C)	
2006		Energy Performance reporting (non-res.,FS>2000m²)
2009		Energy Performance reporting (non-res. 2,000>FS>300m²) Top Runner Housing (Built Single Home suppliers)
2013	2013 Standard, Heat Loss (Ua), Solar Heat Gain (ηa) Coefficient	Primary Energy Use Standard, with 8 climate regions
2015	**Building Energy Conservation Law**	
2016	2016 Standard	**Mandatory** Energy Performance (non-res.,FS>2000m²)
2021		**Mandatory** Energy Performance (non-res.,2,000>FS>300m²)
2025		**Mandatory, all new housing and buildings**

3.1.2.2 Top Runner Program (from consumption by type)

The products covered in the Top Runner Program are chosen by their high energy usage or widespread usage in the community. After the introduction of the program, the targeted products’ energy efficiency has increased and the number of items covered has been expanded to 32 appliances/technologies.

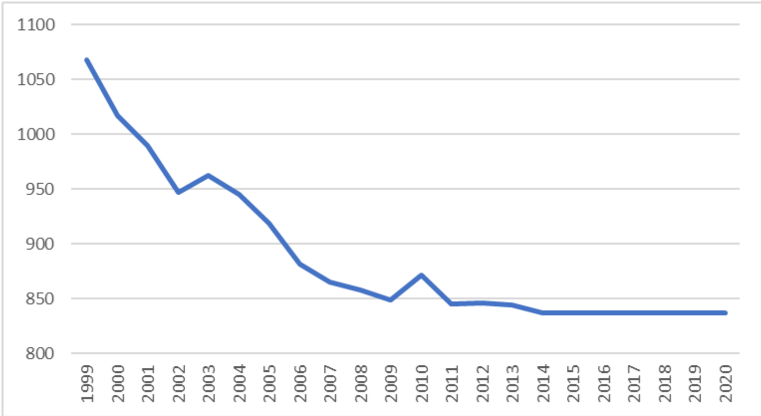


Figure 3-3 Annual AC Electricity Consumption (standard kWh/yr for a unit of 2.8kW)

Energy efficiency standards are set to be achieved within a given number of years based on the most efficient model on the market (the 'Top Runner'). Manufacturers' weighted average product sales are analyzed to evaluate compliance with the standard. Manufacturers must ensure that the weighted average efficiency of the products they sell in a target year achieves the standards. Therefore, not all of a manufacturer's products have to meet the standard, but the weighted average of all products has to be. This flexibility enables manufacturers to provide a wide range of models to meet the market demand while guiding the overall market to higher energy efficiency.

The Energy Conservation Act requires major appliances to achieve target efficiency performance and the performance labeling to be displayed.

Table 3-1: Major appliances and their target EE performance

Appliance	EE target	update	Improved Efficiency
Room Air Conditioner	APF 6.6, with capacity < 4.4kW APF 5.3-6.6, proportional with Capacity	2022	14% more efficient with Capacity <4.4kW 16%-35% more efficient with Cpacity>4,4kW
Refrigerator	kWh consumption, with a product storage volume	2020	22% more efficient than 2014 Standard
Hot Water Boiler	Efficiency ratio to the input energy	2021	5%-7% more efficient
Gas Cooking Stove	Wh: input energy	2019	16%-25% more efficienct
Lighting and bulbs	Lm/W: unit consumption	2019	Overall improvement 293% Fluorescent lamp 6.6% improvement LED lamp 51% improvement

Table 3-2: Housing and Building Energy Efficiency Performance

Segment	Material	update	Improvement
Wall Insulation materials	Standard heat loss prevention performance: Polyethylene foam:0.03232, Glass foam: 0.04156, Slug foam: 0.03781	2020	0.5%-6.2% improvement from 2012 Level
Window Sashes	Heat Loss Prevention Performance Formula, with the window area and the Sache types	2019	3.0%-15.4% improvement from 2012 Level
Double painted Window	Heat Loss Prevention Performance <2 mm; 3.85 2 mm-16 mm: U=一1.00In (thicknee)+4.55 16 mm<: 1.77	2019	7.3% improvement from 2012 Level

3.2 Recent or planned changes including amendments of existing policies

3.2.1 Germany

3.2.1.1 Buildings Energy Act (GEG)

From 2023, Efficiency House 55 will become the standard for new buildings (regarding primary energy demand but not for thermal insulation requirements). From 2025, the Efficiency House 40 will be the standard for new buildings. From 2024, the renovated components of major conversions and extensions to existing buildings must comply with the Efficiency House 70 standard.

From 2024, every newly installed heating system should use at least 65% of renewable energy, which is expected to boost heat pumps and district heating but also biomass. Details are currently defined.

From the beginning of 2026, boilers fueled with heating oil or solid fossil fuels may only be put into operation if certain conditions are met, such as no alternatives using renewable energies being available. For this reason, the maximum operating time of purely fossil natural gas and oil boilers is to be successively limited in the Building Energy Act from 30 to 20 years from 2026, reaching the 20-year limit in 2045. Oil and natural gas boilers installed up to 1996 may still be operated until 2026 at the latest.

3.2.1.2 Federal funding for efficient buildings (BEG)

Details of the grant and loan schemes are adapted from time to time to changes in the market, such as commercial interest rates, renovation costs, and energy prices. Details of the changes implemented in 2021/22 and planned for 2023 are presented in the Annex. Here, we only highlight some important changes. The total amount of government spending for these programs will be increased to € 12 to 14 billion/year until 2026, increased from around € 5 billion/year in 2021/22. The funding amount for very energy-efficient *new* buildings will be reduced, the focus will be on energy efficiency *renovation* of existing buildings in the future. The subsidy for new buildings (efficient house 40 with sustainable class) will be continued until February 28 (2023) on a transitional basis. From March 1 (2023), new buildings are to be subsidized via a new guideline.

A Worst-Performing-Building-Bonus (WPB-Bonus) for the refurbishment of the energetically worst buildings will be 10 percentage points of the investment, based on the worst classes of energy performance certificates. In addition, the WPB-Bonus is to be available not only for refurbishment to Efficiency House 55 and 40, but also for refurbishment to Efficiency House 70 with renewable energy class.

For residential buildings, a new bonus for “serial refurbishment” (SerSan bonus) of 15 percentage points of the investment will be introduced, which can additionally be claimed in the case of refurbishment to efficiency house 55 or 40.

3.2.1.3 Federal funding for efficient heating networks

The German government wants to support and accelerate the decarbonization of heating and cooling networks in Germany with a new financial incentive program. Two areas are targeted with subsidies of 40-50 % of the investment: 1) the construction of new heating networks with high shares of renewable energies and waste heat as well as 2) the expansion and transformation of existing networks.

3.2.1.4 Municipal heat planning

Municipal heat planning is considered important to provide guidance to building owners and energy suppliers on which buildings would be served by either district heating or individual heating in the future. Denmark has a successful history of more than 40 years with this tool, and it was the basis for the very high share of both district heating and renewable energies in heating the country’s homes and buildings (State of Green 2018; Ea Energy Analyses & Viegand and Maagøe 2020). With a revision of the municipal guideline, an impulse subsidy for municipal heat planning has been introduced as of November 1 (2022). The federal government wants to legally obligate the states to have heat plans drawn up for a certain portion of the population and an associated space heating requirement (e.g., 75 percent).

In the new funding priority, the preparation of municipal heat plans by expert external service providers is supported with a grant. If applications are submitted by the end of 2023, the subsidy amounts to 90% of the total eligible expenditure; for financially weak municipalities and applicants from lignite regions, the subsidy amounts to 100%. After that, the grant rates are reduced to 60% and 80% respectively. After the federal law for municipal heat planning comes into force, every obligated municipality should have drawn up a heat plan after three years at the latest. The heat plans are to be updated every five years

Developments in EU policies:
The European Green Deal and Fit for 55 and Revision of the EU Buildings Directive

In the context of the European Green Deal, the EU agreed on the Fit for 55 package aiming at an overall reduction of 55% of the GHG emissions in the EU until 2030. To achieve this ambitious target, efforts in the building sectors need to be reenforced. Against this background, the European Commission published its a proposal for the recast of the EU's Energy Performance of Buildings Directive (EPBD) in December 2021.

- After the Commission proposal, the European Council and the European Parliament have debated it, and an agreement is expected by the summer of 2023.
- The main objectives of the revision are that all new buildings should be zero-emission buildings by 2030 at the latest and that existing buildings should be converted into zero-emission buildings by 2050.
- A "zero-emission building" is a building with a very high overall energy efficiency that requires no or a very small amount of energy, produces no CO_2 emissions from fossil fuels on site, and produces no or a very small amount of operational greenhouse gas emissions.
- An important proposed new element is a mandatory requirement that the worst-performing buildings must improve to a certain energy performance level, closer to today's average level, by certain dates between 2027 and 2033. This is called 'minimum energy performance standards'.
- From 2025, Member States shall introduce 'renovation passports' on a voluntary basis. These include a roadmap on how stepwise energy efficiency renovation can lead to a very energy-efficient zero-emission status in the end.
- Life cycle assessment is to become mandatory throughout the EU from 2027 for large new buildings and from 2030 for all new buildings.
- In addition, there are lots of smaller amendments to improve the effectiveness of the existing provisions, cf. chapter 2.5.1.

Link: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021PC0802

3.2.2 Japan

In June 2022, housing-related legislation mainly including the law about energy consumption performance gain of buildings (hereinafter called as "Building Energy Conservation Law"), the Building Standards Act and the Architectural Act was revised. The revision aims at a decarbonized society by encouraging the installation of renewable energy equipment (e.g., PV panels, solar heat, underground heat) in buildings and the use of wood in buildings. As a result of the revision, the reduction of approximately 8.89 million kLoe in energy consumption for homes and buildings in FY2030 compared to FY2013 is expected.

This series of revisions was realized based on the *Roadmap of the Building sector Decarbonization toward 2050 Carbon Neutral Society* published in August 2021, which is outlined in the next sub-chapter.

Under the current law, the obligation to comply with energy conservation standards is imposed on builders of new constructions or expansion of medium- and large-scale (300 m^2 or more) non-residential buildings, while only notification was required for medium- and large-scale (300 m^2 or more) residential buildings. The current revision expands this obligation to include small-scale non-housing and residential buildings, making it mandatory for all new residential and non-residential buildings to comply with energy conservation standards. Specifically, before construction of a building begins, a “building permit” is issued to confirm that the construction plan complies with the Building Standard Law and other standards, and that compliance with energy conservation standards is inspected together with structural safety regulations.

In consideration of the current situation of small- and medium-sized construction companies and the inspection system, the implementation will start for buildings to be constructed in or after 2025.

	Building Energy Conservation Act (2015)		**2022 Amendment**	
	Non Residential	Residential	Non Residential	Residential
Large (FS >2,000m²)	**Mandatory (2017 Apr.)**	Performance Reporting	Mandatory (2017 Apr.)	**Mandatory (2025 Jun.)**
Medium (300<FS<2000m²)	**Mandatory (2021 Apr.)**	Performance Reporting	Mandatory (2021 Apr.)	**Mandatory (2025 Jun.)**
Small (FS<300m²)	Advisory notice required	Advisory notice required	**Mandatory (2025 Jun.)**	**Mandatory (2025 Jun.)**

Figure 3-4: Expansion of obligation to comply with energy conservation standards

Conformity to the standard will be required for additions and renovations by installing a certain amount of heat-insulating materials and windows in the walls, roof, and windows of the extension, and by installing equipment (air conditioning, lighting, etc.) with a certain level of performance in the extension which meets the requirement of energy conservation standards.

With the expansion of the obligation to comply with energy conservation standards, the scope of explanations to architects regarding compliance with energy conservation standards has also been expanded to include all buildings (new constructions and additions).

The Energy Conservation Law revised in 2008 introduced the "Residential Top Runner System," which obliges businesses that supply more than a certain number of housing units in a year to make an effort to meet, on average, a standard that exceeds energy conservation standards set by the government ("Top Runner Standards") for newly supplied housing by the target year. The current law covers detached houses for sale, custom-built houses, and rental apartments. The current revision includes condominiums as well, with the aim of further improving energy-saving performance.

Housing Suppliers	Standard Design Built Detached Homes	Custom Built Detached Homes	Multi Dwelling Apartments (low, lease/owned, wood or steel)	**Condominiums (mostly high, owned, steel)**
	Housing Developer >150 units	Constructors > 300 units	Constructors >1,000 units	Constructors >1,000 units
Envelope	All units must comply the Act requirements			
Primary Energy Reduction from the Act Requirement **(ZEH Level)**	The average reduction of sold units.			
	another 15%	**another 25%**	**another 10%**	**another 20%**
Year of Application	From 2020	From 2024	From 2024	From 2026

Figure 3-5: Housing suppliers Top Runner Program leading to ZEH Level Performance

3.2.2.1 Promotion of introduction of renewable energy facilities

Renewable energy, mainly solar power generation, has been increasing since the introduction of the Feed-in-tariff (FIT) scheme in 2012, but to achieve the Green House Gas emission reduction target, it is necessary to expand the use of renewable energy in the building sector. On the other hand, since solar power generation is greatly affected by climate and location conditions, it would be more effective for municipalities to promote the installation of photovoltaic power generation based on local conditions rather than for the government to establish uniform regulatory measures throughout the country. Based on this recognition, the current revision requires municipalities to designate areas where solar panels and other renewable energy facilities must be installed (“renewable energy use promotion areas”) and to prepare promotion plans that include the types of renewable energy to be installed and promoted. In particular, height restrictions, floor-area ratio restrictions, and building-to-land ratio restrictions for buildings that conform to the promotion plan will be relaxed in the promotion zone through a special permit system, thereby encouraging the accelerated installation of renewable energy facilities.

A few municipalities implemented higher insulation grades with grant incentives, and Kyoto City has implemented mandatory rooftop PVs on new constructions. Kyoto's ordinance currently applies only the non-residential buildings, with constructors' obligation to advise the owner to install rooftop PVs. Tokyo metropolitan government is planning to implement the same ordinance in 2025.

In addition, architects will be held accountable for explaining the effects of installing renewable energy to building owners. Under this revision, an architect who, in the designated areas, is commissioned to design a building with installed renewable energy must explain to the owner certain matters related to the renewable energy facilities, such as the types and scale of renewable energy facilities that can be installed, the amount of energy created by the installation, and the effect of reducing utility costs.

The feed-in-tariff program with the rooftop PV is already phasing out, and it is best to use rooftop PV-generated electricity to be fully utilized at the premise. Ministry of Land, Infrastructure, Transport and Tourism (MLIT) and the Ministry of Economy, Trade, and Industry (METI) are vigorously promoting the deployment of battery storage in the building sector along with rooftop PV installation. The ministry of environment (MOE) provides a leading net-zero community subsidiary program. The applicant with rooftop PV and battery storage can receive up to 75% of the system/installation costs.

3.2.2.2 Rationalization of building standards to promote wood use, etc.

The use of wood is expected to have carbon fixation and emission reduction effects. Therefore, the rationalization of building standards has been implemented to promote the increased use of wood in the building sector, which currently accounts for 40% of the total demand for wood.

Wood materials have been popular in housing construction in Japan for a very long time. MLIT acknowledged the importance of the wood material promotions in the 2015 White Paper, with the long-term policy on the LCA (Life cycle assessment) low carbon housing or even an LCCM (Life Cycle Carbon Minus) housing. Wood materials carry lower embodied carbon than concrete and steel materials. Good forest management in the wood material industry is perfect for a carbon-neutral target country, such as Japan.

The study group of MLIT has been working on the expansion of the wood material use and necessary building guidelines and code amendments. The structural strength, especially the joint and the section, is one of the challenging issues. There are a few design-load changes, a roof weight considering wet snow conditions, heavier insulated walls and windows, and a rooftop PV panel. These heavier material uses also affect earthquake resistance designs.

The continuous R&D on fire-resistance materials made it possible to use fire-resistance materials, external layers, pillars, and walls made possible to survive a fire for several hours (Fig.3-6).

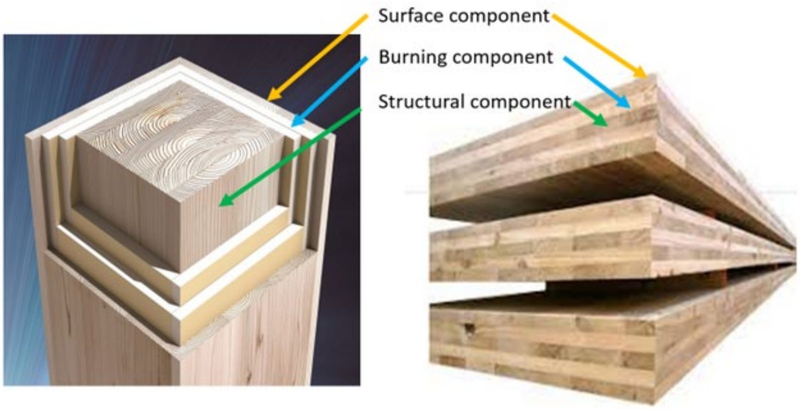


Figure 3-6: Examples of new wood materials in Japan

Fire prevention regulations

Currently, when a large-scale wooden building over 3,000 m^2 is constructed, the walls and pillars must be fireproof, or each 3,000 m^2 must be divided by a fireproof structure. However, if the walls, pillars, etc. of a wooden building are fireproof, the wooden portion must be covered with noncombustible materials such as gypsum board, making it difficult for users to appreciate the quality of the wood. In addition, when measuring off the building with fire-resistant structures, it is necessary to bisect the building, which imposes significant design constraints. Furthermore, all structural elements such as walls and columns are required to be fire-resistant without exception, making it difficult to use wood in parts of the building. Such regulation made it difficult to use wood for large-scale buildings in low-rise areas. There were no detailed standards regarding the required performance of fire-resistant structures according to the number of floors.

The revision relaxes these regulations and introduces a new structural method for large-scale buildings over 3,000 m^2 that allows the design of exposed structural elements, thereby promoting the use of wood in large-scale buildings. For large-scale buildings that are required to have fire-resistance performance, partial wood construction is possible for walls and floors to the extent that it does not interfere with fire prevention and evacuation.

In addition, the fire-resistance performance requirements for fire-resistant construction according to the number of stories have been streamlined for mid-rise buildings, which are in high demand for fire-resistant design using wood construction, and the bottom floor of buildings with five to nine stories can be designed with a 90-minute fire resistance rating.

The new standard also allows the wooden construction of the lower floors by treating the upper and lower floors as separate buildings under the fire prevention regulations, which are divided by high fire-resistance walls and corridors with sufficient separation distance.

Regulation Changes in structural calculation

Under the current law, structural calculation is not required for wooden buildings of 2 stories or less and total floor area of 500 m^2 or less. However, the number of buildings with large spaces has been increasing due to diverse needs, and it has become necessary to ensure structural safety for these buildings.

In addition to expanding the use of wood, the revision lowers the scale of new wooden buildings requiring structural calculation to a total area of 300 m^2 to ensure structural safety.

Under the current law, when constructing a wooden building that exceeds 13 m in height or 9 m in eave height, structural safety must be confirmed through advanced structural calculations (e.g., allowable stress calculations), and only a first-class architect is allowed to design or supervise the construction. This revision expands the scope of buildings that can be designed by a second-class architect using simple structural calculations to include buildings with three or fewer stories and a height of 16 m or less.

3.2.2.3 Promotion of energy consumption performance labeling

The building EE code requires the building EE performance label to be displayed in the advertisement of sales and rent. There are two types of labels, introduced in FY2009:

“Energy efficiency Performance Label” and “Insulation Performance Label”. The “Energy Efficiency performance Label” represents the primary energy consumption by heating/cooling, hot water supply, and lighting. In contrast, the “Insulation Performance Label” means thermal loss prevention by exterior walls, windows, and doors, with recommended levels as the next-generation performance.

Each label has a different grade, the green-colored label is issued by an authorized third-party organization audit, and the constructor's self-audit issues the blue-colored label (Fig.3-7).

Figure 3-7: Housing and Building Energy Efficiency Performance Label

3.3 Future Directions for Meeting the 2050/2045 Carbon Neutral Target

3.3.1 Germany

In Germany, there is no official policy and technology roadmap or pathways for meeting the 2045 Carbon Neutral Target, at least not yet. However, the Climate Protection Law has defined sectoral emissions reduction targets to be achieved year on year until 2030, which will be presented here below.

In addition, there are several scenario modelling analyses of pathways for meeting the 2045 carbon neutral target from various organizations, some with government funding, some private. A number of these have been analyzed in the study on long-term scenario analyses prepared by the GJETC 2021/22 (Obane et al. 2022). These show quite similar technology pathways for a GHG-neutral building sector, including:

- approximately **zero-emission** performance for new buildings
- **highly energy-efficient renovation** of ca. 2 % per year of the existing building stock as well as very energy-efficient appliances, ventilation and cooling systems, and lighting
- **conversion of heating systems** to
  - heat pumps (ca. 60 to 80 % of the stock in 2045)
  - green district heating (ca. 20 to 30 %, with large heat pumps; waste heat from industry, waste incineration, data centers, etc; CHP or heat generation plants using waste biomass; large solar thermal plants; and CHP using green hydrogen), and

- a few % of individual biomass heating in most studies

- **zero-carbon electrification of heat** being enabled by conversion of power generation to almost 100% renewable energy sources.
- rooftop or other buildings-integrated PV is part of this shift to 100% renewables. It also enables charging stations for BEVs. These, as well as heat pumps and district heating with heat storage, must also be used as flexibility sources for the electricity supply network and system.

3.3.1.1 Climate protection law (Klimaschutzgesetz) with sectoral targets

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 forced the government to take immediate action. Thereafter, the targets of the climate law from 2016 were tightened so as to achieve greenhouse gas emissions 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 (cf. tab. 3-3) 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. Since the buildings sector missed achieving its 2020 and 2021 targets by a few mn tons of CO_2 and is expected to miss it in the next few years as well, the two ministries in charge (Economic Affairs and Climate Action; Dwelling, Urban Development, and Construction) released an immediate reaction program in August 2022. It includes the planned actions presented in chapter 3.1.1.

Table 3-3: Annual emission budgets for sectors according to the German climate protection law

[Million t CO_2eq], Source: Climate Protection Law (2021)

Annual emission budgets in million 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

3.3.1.2 Planned energy efficiency law

At the EU level, there are energy saving targets for the Member States as a whole, regulated in the *Energy Efficiency Directive* (EED, currently Directive 2018/2002/EU). These targets are not binding to the EU Member States and not sector-specific, but they are formulated in terms of absolute target volumes of primary and final energy consumption.

The German government is now planning to also add a specific energy efficiency law to the climate protection law. The internal draft of October would set absolute overall target volumes of primary and final energy *consumption* for 2030, 2040, and 2045. For 2045, these would be equivalent to saving 57 % of primary energy and 45 % of final energy compared to 2008.

In addition, the law would obligate the federal government and the federal states to achieve certain new amounts of energy *savings* each year through energy efficiency policies and measures.

Although not sector-specific, it is clear that the buildings sector will be a major contributor for the energy savings targets and measures. In addition, mandatory energy saving targets for the public sector and obligations for medium to large enterprises to install energy management systems or carry out energy audits will be regulated in the law. These obligations also cover energy efficiency in public, commercial, and industrial buildings.

3.3.2 Japan

As for the long-term policy on the building sector decarbonization, three ministries, namely MLIT, METI, and the Ministry of the Environment (MOE) have jointly published a "Roadmap of the Building sector Decarbonization toward 2050 Carbon Neutral Society" in August 2021. The Study group on energy-saving measures toward a decarbonizing society held meetings between April 2021 and August 2021, and the group proposed the roadmap in August 2021. The roadmap expects long-term policies to approach energy efficiency and renewable energy measures with the target milestones in 2030 and 2050.

3.3.2.1 The mid-term (2030) milestones

The energy efficiency building code expects the newly constructed buildings to conform to "ZEH/ZEB Level" to as much as 80% by 2030. The "ZEH/ZEB LEvel" consists of the following:

- The building uses an extra insulation level in the thermal transition coefficient.
- The energy consumption is 30%-40% lower than a mandatory level in medium-large buildings and 20% lower in small buildings.
- More than 60% of new construction single-family homes have rooftop PVs.

Table 5 shows the conformation level of the present market. It is not easy to achieve 80% fulfillment on theZEH/ZEB Level by 2030.

Table 3-4: The EE Code and the ZEH/ZEB Level conformation as of 2019

Residential	**EE Code**	**ZEH Level**
Residential total	81%	14%
Large Apartment	68%	0%
Small-Medium Apartment	75%	2%
Single Family House	87%	22%

Non-Residential	**EE Code**	**ZEB Level**
Commercial total	98%	26%
Large	Mandatory	32%
Medium	97%	21%
Small	89%	3%

3.3.2.2 The long-term (2050) milestones

The roadmap expects the long-term milestone with “the average performance with ZEH/ZEB” in building stocks by 2050, with most buildings and housing have rooftop PVs where engineering and economuically possible.The table below shows the roadmap milestones for residential and commercial buildings in 2025, 2030, and 2050.

Table 3-5: The roadmap milestones in 2025, 2030, and 2050

	2025	**2030**	**2050**
Residential	EE Code applies to all new constructions. Incentives to exceed EE Code requirement (20% primary energy reduction)	Higher EE Code with “ZEH ready” applies to top-runner constructions. 60% of new constructions install rooftop PVs.	The average EE performance of the stock achieves ZEH-Level.
Non-Residential	EE Code applies to all new buildings. Incentives to exceed EE Code requirement (30-40% primary energy reduction)	Higher EE Code applies to all new buildings. 30% reduction: in hospitals, hotels…,40% reduction: in offices and schools (compared to the code primary energy)	The average EE performance of the stock achieves ZEB-Level.

3.3.2.3 The approaches to energy efficiency improvement

The roadmap proposes effective measures according to the market characteristics, “Bottom-up”, “Volume Zone”, and “Top Runner”. “Botttom-up” category represents a lower energy efficiency building/housing market, constructed by mostly smaller size builders. “Volume Zone” category represents most numbers of the constructions by both small and large constructors. The government intends to extend “Top Runner” category from “Volume Zone” Category

Table 3-6: Market characteristics according to roadmap

	Market Bottom-up	Market Volume Zone	Top Runners
Regulation	Most new buildings are to comply with the building EE Code by 2025.	The multi-dwelling apartments comply EE Code. More segments are included in top-runner programs.	ZEH/ZEB is expected for top-runner builders and constructors.
Support	Training programs are provided to help improve skills in insulation installations.	Municipals are expected to lead local market development with incentives with ZEH/ZEB.	Incentives are provided for better insulating materials with the top runner labeling.
Incentive	Incentives are provided for exceeding the code, indicating the upcoming regulation.	Incentives are provided for exceeding the code requirement.	

3.4 Factors/Technologies for Buildings' Carbon Neutral Target

3.4.1 Germany

Greenhouse gas neutrality in the building sector means not only greenhouse gas-neutral operation of buildings (energy consumption for heat and electricity), but also keeping emissions low during construction and demolition ('grey' energy and embedded GHG emissions).

3.4.1.1 Zero-Emission-Building

In low-energy houses and buildings (e.g., Efficiency House 40 standard), a very highly effective thermal insulation and usually also heat recovery ventilation is used, which minimizes heat loss through the building envelope. In the case of a Passive House, it is limited to 15 kWh/m^2/year, and Efficiency House 40 standard requires similar values. In addition, zero-emission houses and buildings cover their remaining energy consumption themselves by generating renewable energy on site. In balance, the energy consumption of this standard is zero. Plus-energy houses actually generate more energy than they consume themselves and can thus compensate for the consumption of other houses. Both heat consumption and electricity consumption are taken into account. Therefore, care is taken to install electric cooling systems only in exceptional cases (e.g., some types of public buildings may need it, even under German climate conditions) in order to keep energy consumption as low as possible.

In addition, heat pumps, solar thermal and photovoltaic systems, and energy storage systems, as well as heating networks based mostly on renewable energy, are primarily used to supply the buildings exclusively with renewable energy.

An important factor is also to expand the electricity mix in Germany with greenhouse gas-neutral renewable energies, so that heat pumps can also be operated in winter with renewable energy, if, for example, the building's own photovoltaic systems do not produce enough electricity. The new renewable energy law of 2022 includes a target of expanding the share of renewable energies in power generation to 80 % by 2030, and the objective is to reach close to 100% by 2035.

3.4.1.2 Wood as a building material in Germany

By using wood or wood-based materials (or renewable raw materials in general) from sustainable sources, a better greenhouse gas balance can be achieved from a climate protection perspective compared to the use of conventional building materials. Current studies determined the possible substitution performance of wood products in different construction methods.

In Germany, the share of timber construction in total construction activity varies greatly from region to region. In the densely forested, southern German states, the share is over 20%, while in the northern states the share is below 15% (Holzbau Deutschland 2020). In the future, it can be assumed that the share of wood used for construction activities in Germany will increase to approx. 25 - 41% by the year 2030 (Mantau et. al. 2017).

With a life cycle assessment, the material flow and energy balance can be drawn up and an impact assessment can be made on this basis:

- The material flow and energy balance determine the amount of wood building materials used and the amount of primary energy (renewable and non-renewable) required to produce them.
- The impact assessment determines the environmental impact based on this, e.g., the greenhouse gas potential (GWP) in kg CO_2 equ. per kg.

The CO_2 stored when trees grow is removed from the atmosphere and temporarily stored (temporary biogenic carbon storage). Buildings made of renewable raw materials, such as wood, act as carbon stores. At the same time, finite raw materials are substituted.

A greenhouse gas accounting study shows that the CO_2 savings potential for single- and two-family homes ranges from 35-56%, while for multi-family homes it is 9-48% (Hafner et. al. 2017).

Therefore, a higher wood usage in buildings is a policy strategy published in the charter for wood 2.0 in 2017 (BMEL 2021). The wood usage in buildings is supported by well-known scientists, experts, engineers, architects and planners through the initiative “Bauhaus der Erde” (Building of the Earth) (Bauhaus der Erde 2022). The local government can set up financial incentive programs and guidelines to use wood or wood-based-materials for buildings – so a lot of major cities have done this already. Furthermore, when municipal land is sold, it can be included in the purchase agreement and calls for urban planning competitions that the buildings are to be constructed in wood – what only a few cities have done so far. It is difficult for municipalities to set targets for the use of wood via other instruments due to restrictions in the German tendering and procurement law.

3.4.1.3 Recycling management

Finally, deconstruction must be considered. This is because if building materials can be separated according to type, they can usually be reused in other products or buildings. This extends the life cycle of the building material as well as the balance of the building material, but also the GHG balance of the products in which the building material is used, is further improved and the use of other resources is avoided (resource efficiency).

3.4.2 Japan

3.4.2.1 The building electrification

There are growing trends and interest in building electrification in the carbon-neutral policy arena, replacing gas furnaces and boilers with electric heat pumps and the gas cooking stove with electric induction heating stoves. While all-electric housing has been a significant choice in the new housing market for two decades in Japan, such building electrification policy is not currently highlighted in the carbon-neutral policies in Japan. The all-electric housing market was fast growing until 2011's great East earthquake. The electric supply shortage has become a new normal until today, and the supply shortage may not go away anytime soon.

However, a decade-long all-electric housing market has learned lessons, especially the deployment in the existing buildings/housing. Many multi-stories buildings and apartments have implemented tankless gas boilers, usually wall-mounted with small projection spaces. The heat pump boiler needs a sizable installation space with little available space. One of the limited choices is the balcony space, where the fire escape code requires enough empty spaces in the balcony to escape to an adjacent room. An additional electricity capacity switching board is usually needed to use a heat pump boiler and electric induction cooking stove.

3.5 Gaps and Need for Further Improvement/Additional Policies

3.5.1 Germany

As the previous chapters have shown, the policy-mix on energy efficiency and decarbonizing heating systems in Germany is already considerably broad and will see a significant boost in ambition and budget funding in the next months and years. However, it still mostly centers around the functions of regulation, funding through financial incentives, and providing information. The sector target in the climate protection law (cf. chapter 3.2.2) provides a high-level policy signal; however, there are no operational targets regarding, e.g., the rate and depth of renovation, or the phase-out of oil and gas heating systems. Therefore, the Wuppertal Institute has analyzed, which comprehensive policy package would be able to accelerate the cost-effective and just building sector transformation to carbon neutrality further. This requires a combination of policies and measures that serve a total of ten functions as shown in the left column of figure 3-6. These add functions such as direction and support, capacity building, and incitement with corresponding policy instruments to the existing policy mix, but also additional or more ambitious instruments in regulation, funding, and information, such as minimum energy performance standards in existing buildings or making building renovation passports available to all inefficient buildings by 2028.

Policy package for energy-efficient and climate-neutral buildings: tasks 2021-2025

	Stopping growth in floor area	Energy efficiency	Green heat
Signal to market	Sector targets Climate and Energy: Fit for 1,5 degrees		
	Targets on maximum floor area	Targets on renovation rate & depth, oil and gas phase out	
Direction & Support	Strenghten governance: dena, BfEE, Länder energy agencies		
	Financial support to local one-stop-shops and city district management		
Cost effectiveness	Step up CO_2 price faster and further after 2025, use revenues to fund the transition; make price pass-through to tenants depend on energy efficiency standards		
Information basis		By 2028: Building Renovation Passports for all buildings built before 2001; Master plans for cities/districts	
Standards & Funding	Support remodelling, moving	Min. energy performance standards in existing buildings, KfW40+ in new build; funding to make it cost-effective, incl. for tenants	
Infrastructure			heat networks and green feed-in
Innovation		For example project aggregation, industrial preconstruction, support for increase in production	
Capacity	Capacity building, digitalisation and communication campaigns		
Incitement	Demonstration and pilot projects, networking and exchange		

Source: Wuppertal Institute 2022

Table 3-7: Proposal for an enhanced policy package for energy-efficient and climate-neutral buildings in Germany, with policy-making tasks for the legislative period 2021 to 2025

(Source: Wuppertal Institute (2022), own translation)

In the following, we briefly explain the policy functions and the concrete measures we see necessary as presented in Figure 3-6. Here, the order of the functions is based on the importance as we see it, whereas it is oriented towards the investment journey in the Figure.

- **Clear signals to provide long-term planning security to markets**. This would require the government to commit to **concrete targets for building energy renovation and the phase-out of fossil gas and oil heating**. From 2025, an annual rate of renovating at least three percent of the building stock to very high efficiency standards should be achieved, along with installation of at least 800,000 heat pumps and 150,000 connections to district heat per year, and an increase of green heat feed-in to the district heating systems of 12 TWh/yr.
- **Stopping the increase in building floor area and resource consumption.** The policy package should not only address energy efficiency of the building envelope and green heat, but also aim to stop the growth in buildings floor area. This growth is connected to most of the new build and hence embedded carbon emissions, and it also requires a lot of scarce resources and land. Here too, figure 3-6 shows that similar policy functions and types of policy measures are needed as for energy efficiency and green heat.
- **Standards and funding – minimum energy performance standards for existing and a phase-out law for fossil oil and gas heating.** The Building Energy Act (GEG) should be revised accordingly. By 2030, all buildings should have reached at least the EPC energy class D, by 2035 class C, and by 2040, class B. The maximum operating time of purely fossil natural gas and oil boilers should to be successively limited more quickly than the government's plans presented in chapter 3.1.2.1 and from 30 to 15 years from 2024, reaching the 15-year limit in 2040 the latest. The financial incentives and financing schemes of the BEG need to make compliance feasible and even attractive. Monitoring of compliance should still be improved.

- **Improving the information basis.** By 2028, each house or building constructed before 2001 that is not yet renovated to at least Efficiency House 70 standard should have a **Building Renovation Passport** that shows how the building could become greenhouse-gas neutral in stepwise or comprehensive renovation. Progress should be recorded in a digital building logbook. The data should be integrated with the **municipal heat planning** discussed in chapter 3.1.2.
- **Supporting and organizing implementation - One-Stop-Shops and City District Management.** These are important to actively approach building owners, reduce practical barriers for building owners by supporting them in organizing the implementation, and may even reduce the costs through bundling of projects that, e.g., allows pre-fabrication. The federal government should fund such organizations in all cities or regions across the country.
- **Strengthening the energy and climate governance:** This concerns the tasks, capacities and funding of the relevant ministries, agencies (such as dena, BfEE, UBA and agencies of the federal states) sa ell as their mutual coordination.
- **Supporting innovation in the construction industry.** Project aggregation in combination with pre-fabrication of renovation components based on new digital tools could make energy efficiency renovation faster and cheaper. The government should provide financial support for wide application of such and other innovative approaches.
- **Qualification, digitalization, and communication campaigns.** There is a severe lack of trained staff for the transformation of the building stock, which needs strong efforts by market actors with government support to train existing and attract new experts. Digital building logbooks and "twins" may reduce time and cost requirements for renovation. The advantages of zero-carbon houses and buildings need to be communicated widely.
- **Supporting the increase in production capacities.** There may be the need for financial support to industry for the conversion from gas and oil boilers to heat pumps and other low-carbon heating systems.
- **Creating incitement through pilot and demonstration projects.** The best would be to have at least one good practice example in each street. Networking and exchange of experiences between home and building owners should be supported.

3.5.2 Japan

3.5.2.1 Energy efficiency retrofit policies and challenges (previously 3.3)

MLIT has been working on the promotion of the existing building market for a decade. In the White Paper of Housing Policy report of MLIT in 2015, MLIT acknowledged many barriers and challenges. Figure 3-8 shows the stock market transaction ratio to the total building transaction, and Figure 3-9 compares with other countries.

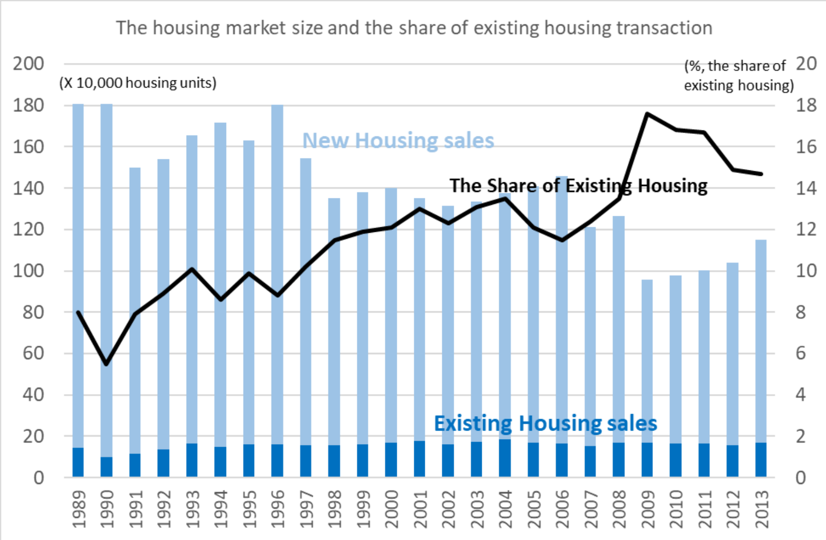


Figure 3-8: The share of the existing housing transaction in Japan

(2013, The White Paper MLIT)

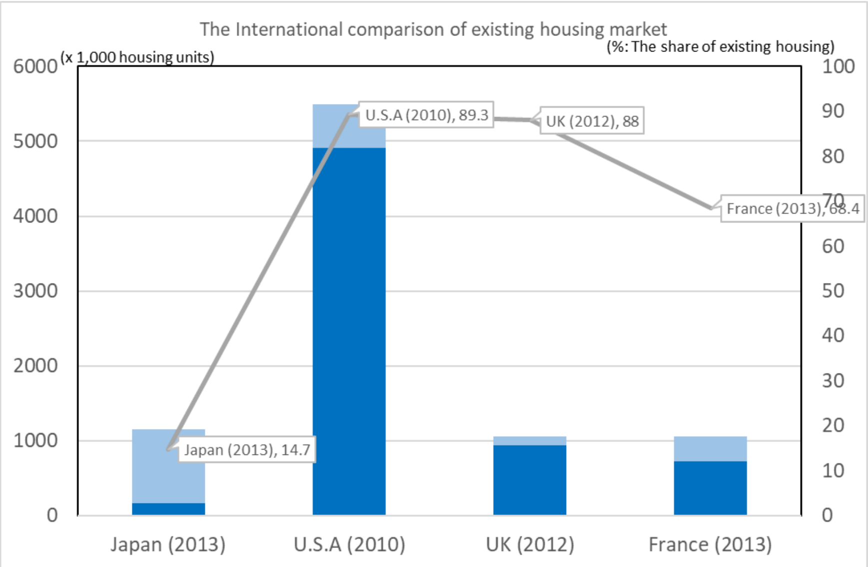


Figure 3-9: The international comparison of the existing housing transactions

(2013 White Paper, MLIT)

MLIT acknowledged that the poor performances in earthquake resistance and the energy efficiency in old buildings are the main reason for a small existing housing transaction. Figure 3-10 shows the distribution of the existing houses' qualifications for the earthquake resistance and energy efficiency codes.

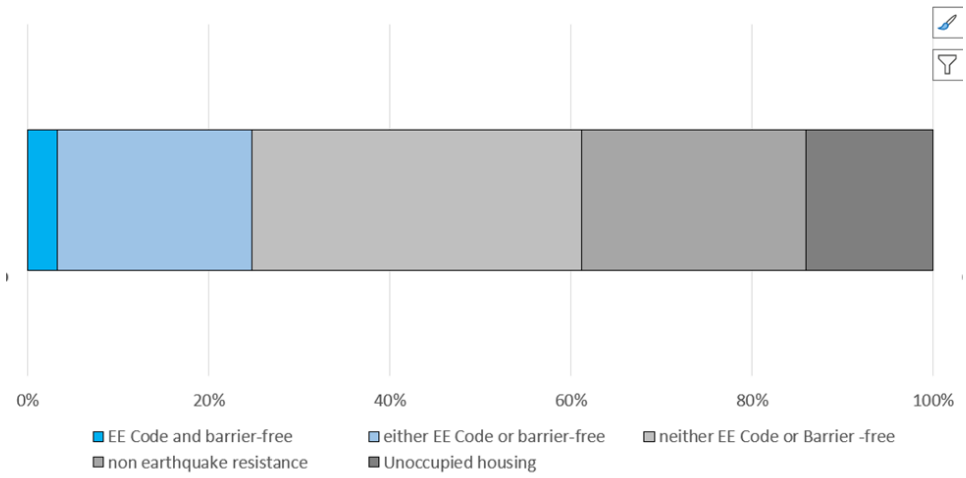


Figure 3-10: The conformation of standards by housing stocks in Japan (2013)

The existing building market should focus on the potentially code-complied buildings. From a buyer's interest, it is hard to tell which building may be suitable for retrofits to comply with the earthquake resistance and energy efficiency codes. Finding a skilled constructor to perform the retrofit work is also difficult, including the appropriate cost estimates. MLIT made progress in the development of the following:

- Licensed support centers for the retrofit, where consumers can receive a free consultation and the work plan quotation check
- Existing Housing Sale Warranty Insurance, an insurance package that covers both inspections and warranty to defects
- Provisions for the registration and licensing tax on existing housing acquisition involving the earthquake resistance work
- A revision of the real estate acquisition tax. The retrofit plan should meet a high level of quality improvement and earthquake resistance code to become eligible for a tax break. In 2015, MLIT reduced the real estate acquisition tax for the existing housing transaction.

MLIT's committee on the housing policy understands that these measures are not enough to accelerate the existing building transactions. There are still serious barriers to overcome. The committee is currently working on the appropriate valuation of the retrofit building in the housing market.

The appropriate valuation of the retrofit building in the housing market

The housing valuation in the Japanese market has been customarily depreciating the housing value within 30 years, no matter what is the housing condition with or without retrofit work, which has discouraged homeowners and real estate agencies from investing in improving housing quality. The study group of the MLIT's housing committee has found in the 2020 report that potential buyers want to acquire good quality existing housing with fewer costs than a newly built one, and many buyers want to invest in the retrofit of the existing housing. The housing market stakeholders should work together to change this customary valuation of the existing housing, reflecting the retrofit values so that many buyers and real estate agencies would willingly invest in the retrofit.

As a result of the two-years long MLIT's committee discussion, a summary report proposed guidance in the further developments of policies in:

(1) improving building evaluations methods to establish a good second-hand building market,

(2) creating a supply chain with quality housing,

(3) financial assistance measures to promote the second-hand housing market,

(4) stimulating a better single-family rental house market,

(5) more active participation by local municipalities in the second-hand housing market.

3.5.2.2 The approaches of renewable energy use promotions

The roadmap toward 2050 building decarbonization expects the rise of renewable energy use as the primary pillar and energy efficiency improvement. Using onsite renewable energies will realize the ZEH/ZEB building.

Rooftop PV deployment

The total rooftop PV installation is over 2 million single-family housing, which is about 7% of the single-family housing stock of 27 million. About 70 thousand newly built single-family housing have rooftop PVs, and 50 thousand existing houses are installing rooftop PVs yearly. Despite the continuous decrease in installation cost and popularity, rooftop PVs are not growing fast enough. The study group of the 2050 building decarbonization discussed the mandatory requirement of the rooftop PV on the new buildings, while there are still obstacles to overcome. One of the positive pathways is the municipal ordinance's lead. The building code was amended to allow more flexibility in the municipal's jurisdiction with an additional energy efficiency requirement through ordinances. A few municipalities implemented higher insulation grades with grant incentives, and Kyoto City has implemented mandatory rooftop PVs on the new construction. Kyoto's ordinance currently applies only the non-residential buildings, with constructors' obligation to advise the owner to install rooftop PVs. Tokyo metropolitan government is planning to implement the same ordinance in 2025.

The feed-in-tariff program with the rooftop PV is already phasing out, and it is best to use rooftop PV-generated electricity to be fully utilized at the premise. MLIT and METI are vigorously promoting the deployment of battery storage in the building sector along with rooftop PV installation. The ministry of environment (MOE) provides a leading net zero community subsidiary program. The applicant with rooftop PV and battery storage can receive up to 75% of the system/installation costs.

Promotions of solar heating hot water

Along with the deployment of rooftop PVs, solar heating hot water has been in the market for several decades, but the market is tiny and is not growing either. Tokyo metropolitan government promoted more solar heating panels for smaller rooftop housing and commercial building between 2012 and 2014, but the focus quickly shifted to rooftop PV.

Another renewable energy promotion policy is looking at the broader application, such as sharing renewable energy across multiple buildings. Aggregated energy demand/supply management is one expected business model to increase.

4 Comparison of Key Results of the Study

4.1 Building Stock Characteristics

The study on the building energy consumption of Germany and Japan quickly highlighted the difference in the energy use sector, notably for space heating. The difference is associated with two factors; one is the geographical latitude of the countries, and the other is the housing heating system.

Fig. 4-1 shows the average household energy consumption comparison, and the difference is in the space heating energy consumption.

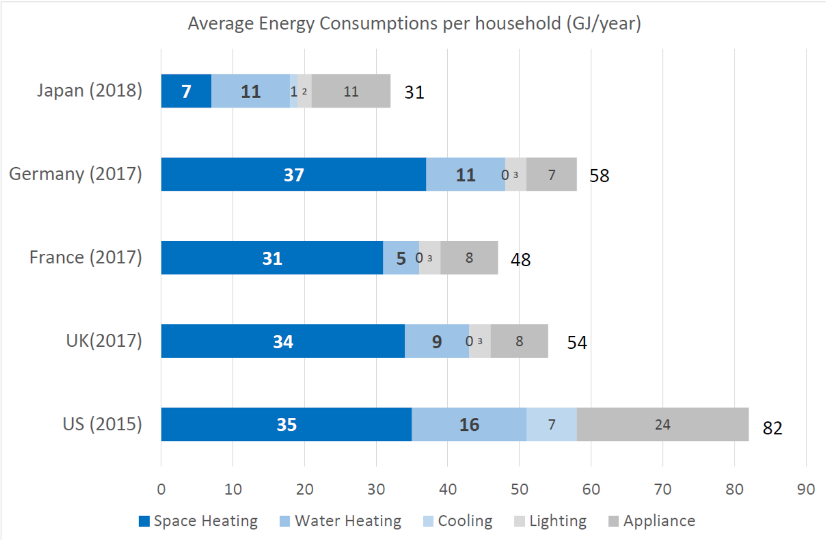


Figure 4-1: Comparison of average energy consumption per household (GJ/year)

Fig.4-2 illustrates the geographical location in the latitude. Germany is located at a much higher latitude. In fact, the most southern town in Germany is located at the same latitude as the most northern town in Japan.

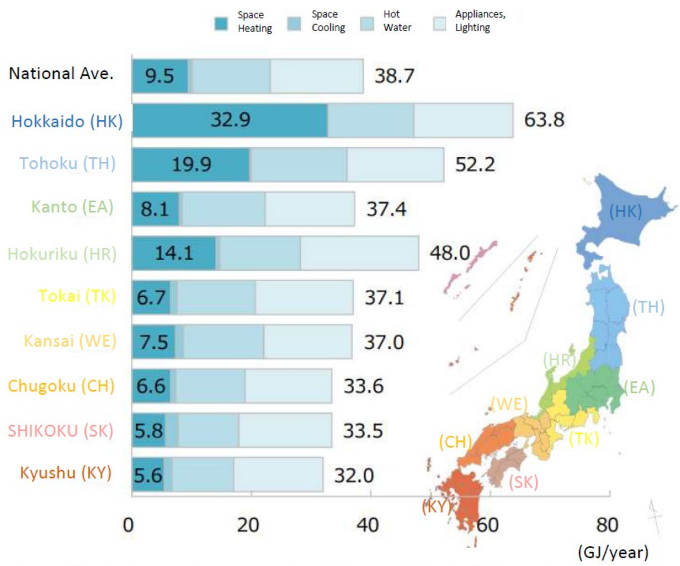
Figure 4-2: Geographical latitude of Japan

The heating degree in Germany is around 3,500-4,000-degree days while it is 1,000-degree days in Japan. Most of Japan is in a very warm and humid climate, comparable to West Europe/Africa. Tokyo's latitude is slightly southern to Algiers (Algeria) and slightly northern to Casablanca.

Fig.4-3 shows the energy consumption in different geographical regions. The northern region, Hokkaido's energy consumption is much closer to the consumption in Germany.

The most populated regions, Kanto (East), Kansai (West), and Chubu, are all in warmer regions. 70% of the Japanese households are in these three regions. With such a warmer climate, most houses use partial/intermittent space heating. Central heating is hardly found in Japan, except in the northern region, Hokkaido.

This difference in space heating leads to different energy conservation measures. Space heating energy conservation is the priority target in Germany. On the other hand, Top Runner program for lighting/appliances, including separate room air conditioning and hot water boilers, is an effective choice in Japan.



(Source)The recent energy consumption in the residential sector (Jyukankyo Research Institute) / The Study Group of Energy Consumption Performance in the Building Sctor (Vol.5, Feb.22nd 2018)

Figure 4-3: Different Energy Consumptions along different climate regions in Japan

(1) Renewable energy use

The study shows the same policy trends in new construction with tighter envelopment and more efficient HVAC in Germany and Japan. Both countries share the same policy trend to use more renewable energy, but the implementation measures are different. Germany requires 65% renewable energy use in the building code. In Japan, the policymaker needs to consider a higher multi-dwelling housing share (40%) in urban cities and the different climate conditions along the nation, so the municipals are leading the renewable deployment programs. Tokyo metropolitan government and Kyoto city are the initial municipals to implement mandatory roof-top PV in new construction.

(2) Housing retrofits

German building retrofit policy focuses on energy efficiency and renewable deployment, with financial support (subsidies/grants/low-rate loans) and professional advice. Energy cost savings and better market valuation with the efficiency labeling system (Energy Performance Certificates) can recover retrofit investments in less than twenty years.

In Japan, the building policymaker (MLIT: Ministry of Land, Infrastructure, Transportation and Tourism) targets retrofits in owned houses constructed after 1980. Pre-1980 housings may better get demolished and newly constructed. As housings get older, their residents are also becoming elderly. When such residents consider a housing retrofit, they usually have three choices: convenience/comfort, energy conservation, and barrier-free accessibility.

Most residents exchange a room air conditioning and a hot water boiler in a 10-15 year-cycle. There is less incentive to explore double/triple paned window replacement and better insulation in the wall/roof/floor. Policies aiming at incentivizing such retrofit measures potentially increase the number of residents willing to invest time and money for larger/less familiar measures.

One of the hurdles in the energy conservation retrofit is the longer investment recovery time and less urgency as an individual. Such a hurdle is not limited to housing retrofit but is frequently observed in the non-residential sector's higher equipment/industrial machine replacement.

There is also a logistical hurdle. An effective retrofit program requires a good assessment and planning, associated with additional costs, which become a problem for both the resident and the service provider. In Germany, these costs are subsidized with up to 80%.

ESCO (Energy Service Company) and EaaS (Energy as a Service) models can be explored so that such additional logistic costs are minimized and levelized across a long service payment. The policy needs to show the long sustainable retrofit market with becoming the initial demands in the government/municipal buildings retrofits so that the service company can survive in the early stage. Such a government/municipal initial demand can also help boost renewable energy and EV charging business.

4.2 Policies and strategies

Japan and Germany have a long history of implementing energy conservation laws aimed at improving energy efficiency and reducing energy waste. While Germany introduced its first building related legislation as early as 1977 with the *Heat Insulation Ordinance* with prescriptive values for the energy efficiency of building envelope components and heating systems, the Japanese policies had a more general focus on the energy performance of appliances with its *Top Runner Program* launched in 1998. This different approach can partly be understood by the fact that the share of energy used for heating is not as high in Japan compared to Germany, because most Japanese only heat or cool the room they are using at a certain time, and the average per capita floor area is lower compared to the Germans – approximately one-fifth compared to Germany (Output Paper, GJETC 2020). Contrary to Japan, the energy used for heating is accounting for a large share of the overall energy consumption in a standard German household. Accordingly, measures and policies aiming at the improvement of the insulation of the building envelope are considered of utmost importance: From 2001, an overall building energy performance approach for new buildings was added, as well as component energy efficiency requirements in case of major renovation. In Japan, the newly introduced *Building Energy Conservation Law (2017* revised in 2022*)* applies the *Top Runner Program* introduced in

1998 for appliances also to dwellings by imposing an average efficiency standard on owners of numerous housings.

Against the background of raising the ambition level to cope with the global warming, both countries have also intensified their efforts to increase the energy performance of the buildings. In Germany, after several rounds of improvement of the standard for new build, it will reach nearly zero-energy building standards in 2025. Importantly, German legislation is also often influenced/pushed by EU regulations that have been tightened following the launch of the Green Deal and the soon expected agreement on the fit for 55 program aiming, among others, at GHG emission reduction in the building sector.

Major points in common

The overall goal of both countries' policies is to reduce the energy consumed in the building sector. However, in Japan the focus is more on new buildings and the improvement of the energy performance of appliances, while in Germany the improvement of the insulation (of the envelope) of both new and existing buildings is considered important.

Germany is now strongly promoting the use of heat pumps. Integration of renewable energies is also important for both countries (however to different degrees), with a focus on incorporating solar, wind, and other sustainable sources into new and existing buildings. Both Japan and Germany offer financial incentives for renovation and maintenance of high energy performance standards in buildings, including tax credits and subsidies. In terms of appliances, Japan has the *Top Runner* program to increase energy performance and efficiency, while the EU has implemented the *Ecodesign* program to promote environmentally-friendly design in products, which is immediately binding for all Member States, including Germany.

Furthermore, Japan and Germany both acknowledge the importance of increasing the share of wood among the construction material to reduce the GHG emissions in the construction process.

Major differences

Japan and Germany both prioritize energy efficiency and sustainability in their building sector policies and strategies, but there are some key differences between the two countries. Japan places a greater focus on appliances, such as air conditioning and lighting systems, as a means of improving energy efficiency, whereas Germany places more emphasis on improving the insulation and overall energy performance of its building stock, and on heating systems. This difference in focus may be a reason why the *Top Runner* standards for air conditioners are more advanced than the EU Ecodesign standards, while building code requirements for overall energy performance and many components are much closer to ZEB/ZEH performances in Germany than in Japan, even for similar climate zones, and will be made more ambitious already in 2025, compared to 2030 in Japan. Germany has more specific goals for the integration of renewable energies in the building sector and offers a larger range of financial mechanisms to encourage building upgrades and renovations. This includes subsidies, tax credits, and low-interest loans, while Japanese policies rely more on mandatory regulations and building codes. Despite these differences, both countries are committed to reducing their carbon footprint and promoting sustainable building practices.

Table 4-1 summarizes the relevant of both countries with regard to (a) Energy Performance Requirements, (b) Energy Performance Certificates, (c) Performance standards, (d) integration of renewable energies, (e) financial incentives, (f) energy advice, (g) energy management requirement and (h) Lifecycle Assessment.

Table 4-1: Comparative overview of policies aiming at improving the energy performance of the building sectors in Germany and Japan

	Type of policy	Germany	Japan
	Energy performance requirements	*Building Energy Act (2020):* • Compliance with energy performance for (a) new buildings and (b) existing buildings undergoing major renovation • integration of renewable energies	*Building Energy Conservation Law (2017, updated in 2019 and 2021)* • mandatory min. envelope performance • standard average efficiency standard on housing builders • additional efficiency levels for ZEH/ZEB level with incentives
		Revision of Building Energy Act (2022): new or stronger efficiency standards • 2023: Efficiency House 55 Standard for new build • 2025: Efficiency House 40 Standard for new build • 2024: Efficiency House 70 Standard for renovation or extension of existing houses • 2024: at least 65% renewable energies in newly installed heating systems	*Revision of the Building Energy Conservation Law (2022) to comply with 'decarbonized society' plan* • improve energy efficiency • increase use of RE and use of wood Energy Conservation Law • specific targets for (a) appliances and (b) building material • compliance with energy conservation standards also for **new** medium- and large-scale residential buildings → building permit as certificate for meeting the standard • to be implemented by 2025 • Requirements for renovation (insulation/ high-level performance appliances)
	Energy performance certificates	*Energy Performance Certificate (EPC)* • ranging from A^{+}-H for residential buildings • obligation to present to interested parties at sale or lease • highlights deficiencies of the building and offers recommendations for energy renovation	Energy consumption performance label Insulation Performance label
	Performance standards for appliances	*Ecodesign* • necessity to ensure energy efficiency and recyclability • inform about possible environmental externalities • analyze product lifecycle	*Top-Runner (1998), revised 2022:* • increase energy efficiency of standard appliances • revised 2013 to also include e.g., (commercial) refrigerators, electric water heaters, light-emitting (LED) • 2015 revision expanded to building materials. • The government is trying to accelerate the standard updates onward.

	Integration of Renewable Energies	• certain percentage of overall energy performance of new buildings/ houses must be covered by renewables • 65% from 2024 in new heating systems (according to revised GEG)	• obligation for municipalities to increase the share of renewable energies by indicating
	Financial incentives	• since 2005: loans and grants for energy efficiency renovation and integration of renewable energies • federal funding for efficient buildings including renewable energies: in 2022, 5 billion Euros • plans to increase volume to 12 to 14 billion Euros/year from 2023 until 2026 • Worst-Performing-Building Bonus (WPB) • Serial Refurbishment Bonus (SerSan-bonus) • Efficient heating network program • Support for municipal heat plans (covering 90-100% of cost)	• Grants for energy efficiency renovation (Efficient Windows/doors replacement, Wall/Roof Insulation, Efficient Boiler Replacement, each replacement may receive 9,000JPY-48,000JPY, up to 300K per household) • 75% of the cost for the installation of a rooftop PV and battery storage
	Energy advice	Professional energy consulting (subsidized as well) as prerequisite for financial incentives for renovation measures	architects must be capable of informing about the integration of renewable energies for (new) buildings
	Energy management requirements	Following the EU's energy efficiency directive from 2012 (Art. 8), Germany introduced a requirement for companies defined as not being small and medium enterprises to either have a regular energy audit or an energy management system. This includes buildings.	*Energy Conservation Law (1979):* • obligation for regulated facilities to appoint an energy manager • necessity to report energy consumption and develop reduction plans
	Lifecycle Assessment	Increase of wooden material	Increase of wooden material

5 Conclusion: Learnings and Recommendations

This study has taken stock of building stock characteristics, energy intensity, and energy consumption in both countries, Germany and Japan, in chapter 2, and of existing policies and their recent and planned changes, as well as the strategies and factors towards carbon neutral targets in both countries in chapters 3.1 to 3.4. In chapter 3.5, we identified gaps in the existing and planned policies for actually achieving the carbon neutral targets and made some recommendations on how the policy mix could be enhanced further. Chapter 4 compared the findings for both, building stock characteristics and policies and strategies.

Based on these analyses and findings, this chapter draws some conclusions on potential mutual learnings between Germany and Japan, summarizes the policy recommendations for both countries individually from chapter 3.5 (5.1), adds recommendations on potential cooperation between both countries in terms of innovative technical solutions and policies (5.2), and ends with suggestions for further research needs (5.3).

5.1 Learnings

Policies and measures

Germany can learn from some aspects of Japan's approach to implementing energy-saving measures in the building sector. Japan places a strong emphasis on appliance energy efficiency, which is an area where Germany could potentially improve its policy efforts in addition to the EU's Ecodesign regulation and labelling. Additionally, Japan's experience with energy management systems and all-electric housing could provide valuable insights for Germany as it continues to promote electrification in the building sector. Finally, programs that promote wood construction in Japan are also very interesting for Germany. In this regard, the profound experience Japan has concerning wooden building construction and particularly the country's knowledge on how to reduce the risk of fire, is useful for Germany's building sector. By incorporating these approaches, Germany could potentially enhance its efforts to reduce its carbon footprint and promote sustainable building practices.

Japan, on the other hand, can learn from Germany's focus on the overall energy performance of the building stock. Germany places a strong emphasis on improving insulation, heat recovery ventilation, and incorporating renewable energies towards net-zero-energy buildings, which can have a significant impact on reducing energy waste and improving sustainability. Japan could benefit from adopting these approaches to strengthen or complement its existing measures, such as mandatory regulations and the *Top Runner* program, to drive improvements in energy efficiency. Additionally, Germany's extensive system of financial mechanisms for investments and energy advice, such as grants, subsidized loans, and tax credits, can provide a model for Japan to incentivize building upgrades and renovations. By incorporating these strategies, Japan could potentially enhance its efforts to reduce its carbon footprint and promote sustainable building practices, while also increasing the comfort-level of Japanese housing and buildings.

5.2 Policy gaps and recommendations

From a German point of view, although major improvements of existing policies are planned, both the recent as well as the planned policies are lacking operational targets (e.g., annual rate/depth of energy renovation, phase-out of oil and gas heating). Also, in addition to improving the energy performance of the building sector, it is also important to stop or at least reduce the increase in building floor area and by that also tackling embedded carbon emissions (protection of resources and land).

In order to make retrofit measures more attractive and the progress more transparent, it is recommended to (a) increase financial incentives, (b) ensure monitoring and (c) show the state of a building's renovation by introducing, for example, a *Building Renovation Passport*. Supportive structures, such as One-Stop-Shops, would also further facilitate the renovation process.

One major remaining problem in the Japanese building stock concerns the poor performance in earthquake resistance and energy efficiency of many buildings and houses. Here, it is important to amend the regulations to equally incorporate both aspects into the building code. Appropriate valuation can be identified as another major challenge, because often the buyers cannot judge which buildings are suitable for retrofit. Moreover, the building code requires to comply the newest regulation upon the retrofit work; regardless whether the work may not involve the non-fulfilling section. There are too many simple retrofit work opportunities, such as a simple additional façade modification and an external wall insulation, passed with excessive costs. Closely connected to the problem is the lack of skilled workers to take care of the renovation measures. Communicating the health and comfort benefits of improved thermal insulation and shading may help to overcome the barrier that energy efficiency retrofits may not be cost-effective based on energy savings alone.

The increase of renewable energies at buildings also poses a problem because of height restrictions inscribed in the building code. However, this barrier could easily be adjusted by amending the regulations respectively.

5.3 Potential for German-Japanese cooperation

Cooperation between Germany and Japan on energy efficiency in buildings and the policies and measures to support it is nothing new. A Memorandum of Cooperation has existed between the construction ministries of the two countries since 2013 and has also been extended to the research level between the BBSR in Bonn and Berlin and the Institute for Building Research in Tsukuba. Within the framework of this cooperation, a basis of trust and a state of knowledge on the respective standards and developments has emerged, which seems to present a very fruitful basis for further exchange. Because Germany introduced some types of policies on energy efficiency in buildings earlier on, Japan has been able to gain inspiration for its own energy and environmental policies, inter alia, from Germany's set of policies in the past.

The principle of 'Inform, Support, Regulate based on Research' has established itself in German building energy policy. A similar approach seems to apply in Japan as well, so that an exchange on the respective political measures is possible along these lines and based on the prototypical policy package outlined above. In all policy areas, parallels can already be seen in the work, even if the levels are still different. The aspects discussed above in chapter 5.1 on mutual learnings could provide ideas for exchange and cooperation.

The GJETC has already contributed to this exchange through a working group paper published in 2020 (Rauschen et al. 2020), and through discussing policy approaches and recommendations at the recent stakeholder dialogue on "Exchange on Policy Frameworks that support the Transition to a Carbon Neutral Building Sector in Japan and Germany", held on 3rd of March, 2023 in Tokyo and online.

A further approach to the exchange may build, e.g., on German experience with the work of energy and climate protection agencies. In Germany, the work of such agencies for the efficient implementation of political goals is important at the federal, state and local levels. The agencies manage to build up competences and implement projects professionally over longer periods under public or partly public sponsorship.

The German side in particular can benefit from the Japanese experience of Smart City projects. In addition to heat pumps, which are highly developed in Japan, their use combined with photovoltaics in such settlements is a model for Germany, where urban neighborhoods are still very heat-oriented.

Therefore, connecting German knowledge of and technology for building shell energy efficiency and Japanese knowledge of and technology for BEMS/HEMS and Smart Cities could provide even better energy performance in both countries, and opportunities for implementation in other countries too.

This is one potential topic for a future innovation roundtable by the GJETC. These innovation roundtables bring together experts from industry and research, to discuss possibilities for concrete cooperation projects in the development and testing of new technologies or solutions.

Another potential topic regarding building sector decarbonization for an innovation roundtable could be "Cost-efficient Refurbishment in Building Stock with Serial Components". It could combine German building design and envelope technologies with Japanese experiences in serial and prefab housing. Concrete objectives could be demonstration of industrial construction, digital design tools, and process optimization, while advancing the use of low embedded carbon designs and materials.

5.4 Further research needs

The goal of reducing the cost of energy renovation and accelerating it in times of shortage of skilled workforce through prefabrication, digital design tools, and process optimisation mentioned at the end of the last section is also one important area of further research needs. This has already been identified in a previous output paper (Rauschen et al. 2020).

Regarding the building stock and strategies towards decarbonization, questions include:

- What are the most appropriate building concepts and energy performance levels in different climate zones?
- What are even current energy performance levels for comparable buildings in comparable climate zones?
- How can cost-effectiveness of energy-efficient/low-carbon buildings and renovations be further improved?
- What does this mean for the energy standards of building components and installed systems?
- How much energy can be saved through HEMS/BEMS and energy sufficiency?

- How can buildings be made a source of flexibility for electricity supply?
- Which other benefits can be achieved, e.g., for health and productivity?
- How can embedded carbon be assessed and tackled?

In the field of policies, a more in-depth analysis seems also useful on how the policy packages for energy efficiency and decarbonization in buildings can be made more effective. This analysis could particularly address, whether the suggestions for new or enhanced policies and measures outlined in chapter 3.5 are applicable in both countries and beyond, albeit with adapted choices in case of policy alternatives and with country-specific adaptations of the typical instruments. What can be mutually learnt for making energy/material efficiency (and sufficiency) as well as renewable energy policies for new build and energy-efficient/low-carbon renovation more effective in both countries?

The complexity of restructuring the demand side of the energy market during the energy transition in Japan is comparable to that in Germany. This raises the question, whether especially the cooperation on a new (polycentric) governance structure, according to the principle “Efficiency First”, could be intensified? For example, do both countries need a central coordinating institution (agency) for energy efficiency (and sufficiency) policies with strong financial and staff resources?

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7 Appendix

7.1.1 Supplements to chapter 2.5.1

7.1.1.1 Life-cycle Assessment and Grey Energy (non-renewable primary energy) – Existing Policies: System limits (using the example of QNG)

- The table shows which processes and phases are included in the system limit and therefore incorporated in the evaluation and which processes and phases are excluded. The designations and descriptive information from modules A to D refer to DIN EN 15978.

LIFE PHASES	A 1–3			A 4–5		B 1–7							C 1–4				D
	PRODUCTION PHASE			ERECTION PHASE		USE PHASE							END OF THE LIFE CYCLE				BENEFITS AND LIABILITIES OUTSIDE OF THE SYSTEM LIMITS
	RAW MATERIALS PROCUREMENT	TRANSPORT	PRODUCTION	TRANSPORT	ERECTION/INSTALLATION	USE 1	MAINTENANCE 2	REPAIR	REPLACEMENT 2	MODERNISATION	ENERGY CONSUMPTION DURING OPERATION	WATER CONSUMPTION DURING OPERATION	DISMANTLING/DEMOLITION	TRANSPORT	WASTE RECYCLING	DISPOSAL	POTENTIAL FOR REUSE, RECOVERY AND RECYCLING
Modules in accordance with DIN EN 15978	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D

Delimitation of the different regulations: Life cycle assessments must be prepared for the following building certifications, among others:

- DGNB, BNB: without inclusion of module D
- DGNB: with inclusion of module D

→ No direct comparability of the results of the different LCA calculations!

When calculating a life cycle assessment, the following components are recorded and documented in a component catalog (KG – German cost categories)

Complete building structure incl. unheated areas (basement, underground parking, etc.)

- KG 320 Foundation, substructure
- KG 330 Exterior walls/vertical building structures, exterior
- KG 340 Interior walls/vertical building structures, interior
- KG 350 Ceilings and horizontal building structures
- KG 360 Roofs

Building services, with the installations necessary for the use of the building

- KG 410 Sewage, water, gas installations
- KG 420 Heat supply systems
- KG 430 Air-conditioning systems
- KG 440 Electrical installations
- KG 450 Communication, safety and information technology systems

- KG 460 Conveyor systems

  In the case of complete modernization, the materials and components that continue to be used are included with zero in the determination of the proportional balance sheet values of modules A1-A3. Newly installed materials and components are accounted for as in the case of new construction.

7.1.2 Supplements to chapter 3.1

7.1.2.1 Federal funding for efficient buildings

- Definition Building heating network up to 16 buildings and up to 100 WE published in October 2021.
  - 30 % subsidy if at least 55 % renewable energy and waste heat
  - 35 % subsidy if 75 % renewable energy and waste heat
  - heat network connections 30 % subsidy if 25 % renewable energy and waste heat in the network or primary energy factor max. 0.6
  - 35 % subsidy if at least 55 % renewable energy and waste heat or primary energy factor max. 0.25 or transformation plan is available
- Waste heat can be credited to reach the efficient house standard
- As of 01.02.2022, the subsidy from efficient house 55 was discontinued.
  - The renewable energy and sustainable classes were also discontinued for some time.
- In the case of selfmade work, material costs are to be eligible for grants funding again if an energy efficiency expert certifies that the measure has been carried out professionally.
- For municipalities, the maximum cumulation limit will be raised from 60% to 90%.
  - The requirement that at least three bids must be obtained for subsidized measures is softened by adding a note stating that this requirement may be waived in justified cases.
- The requirement to achieve the renewable energy class is increased from 55% to 65% of coverage from renewable energies or unavoidable waste heat.
  - Unlike before, heat recovery from a ventilation system and the use of green hydrogen will also be able to be counted in the renewable energy class.
  - The use of biogas, on the other hand, can no longer be counted.
  - When connecting to a heating network, it should always be possible in future to apply a flat-rate renewable energy share of the heating network of 65%.
  - A new requirement for achieving the renewable energy class is the use of a ventilation system with heat recovery.
- In the future, it will also be possible to apply the sustainable class for the renovation of residential buildings.
- With the exception of the efficiency house "Denkmal" (historic listed building), all efficiency houses must be low-temperature ready; a supply temperature of 55°C must not be exceeded during design and operation.
- Previously, power supply systems (e.g. photovoltaic systems) could be co-financed for efficiency houses and is now completely abolished.
- Biomass systems may only be used in subsidized efficiency houses if they do not exceed a fine dust emission of 2.5 mg/m³.
- As of 01.01.2024, requirements for noise emissions from the outdoor unit (at least 5 dB lower than specified in the Ecodesign Regulation) apply to subsidized efficiency houses with air-to-water heat pumps.
  - As of 01.01.2026, these requirements are to be tightened (at least 10 dB lower).
  - In addition, only natural refrigerants may be used in heat pumps from the beginning of 2030.

7.1.2.2 Individual measures in Federal funding for efficient buildings

- The lower limit of eligible costs (minimum investment volume) is raised from €2,000 to €5,000 and from €300 to €1,000 for heating optimization measures.
- The promotion of fuel cells powered by green hydrogen is newly included with a subsidy rate of 25% (plus 10% exchange bonus, if applicable).
- In the case of subsidies for heat pumps or biomass heating (also in addition to an existing or new fossil heating system), the building to be supplied must be powered by at least 65% renewable energy after the measure has been implemented.
- In the case of subsidies for heat generators, the rental costs for a temporary heating system after a heating system defect can be subsidized for a period of up to one year.
- When subsidizing heat generation systems, a heating load calculation and hydraulic balancing is always required.
- If an internet connection and a technical interface on the device are available, the connectivity of subsidized heating systems must be established.
- The subsidy for heating optimization is limited to small buildings (at least 5 residential units or up to 1,000 m² in case of non-residential buildings).
  - In addition, fossil heating systems older than 20 years will no longer be subsidized for heating optimization.
- Biomass heating systems can only be subsidized if they are combined with a solar thermal system and do not exceed a fine dust emission of 2.5 mg/m³.
  - The innovation bonus for biomass systems is cancelled.
- Biomass heating systems must have seasonal space heating utilization rates of 81% from 01.01.2023 (today: 78%).
  - In addition, the biomass used must comply with sustainability requirements.
- The subsidy rate for the construction of building networks will be increased from 25% to 30%.
  - At the same time, the subsidy rate for the construction of building networks using biomass will be reduced to 20%.
- Subsidized building networks must be operated with at least 65% (previously 55%) renewable energies or unavoidable waste heat.
  - Biomass systems in building networks are only eligible for funding in bivalent form in conjunction with other renewable energies or if there is no possibility of bivalent generation.
- In the future, the construction of building networks must always be accompanied by an energy efficiency expert.
- For the connection to a heating network, there are no longer any technical requirements for a renewable energy share or for the primary energy factor.
  - In addition, the subsidy rate for connection to a heating network will be increased from 25% to 30%.

7.1.2.3 The funding for efficient heating networks program is divided into four modules that build on each other:

- Eligible for funding in Module 1 are transformation plans and feasibility studies for the transformation or new construction of heat network systems.
  - These must be geared to supplying heat to more than 16 buildings or more than 100 residential units.
  - Systemic funding covers the new construction of heat grids that are fed by at least 75%

    renewable energies and waste heat, as well as the transformation of existing infrastructures into greenhouse gas-neutral heat grids.
    - A maximum investment subsidy of 50% is granted
- The funding in Module 2 basically covers all measures from the installation of the generation plants and heat distribution to the transfer of heat to the buildings supplied.
    - A maximum investment subsidy of 40% is granted for investments in generation plants and infrastructure.
- The systemic approach is supplemented by individual measures in module 3.
- In addition, Module 4 provides an operating cost subsidy for the generation of renewable heat from solar thermal systems and from electricity-driven heat pumps that feed into heating grids.
    - This subsidy applies both to new construction of heat grids and to transformed existing grids.

7.1.2.4 Municipal heat planning

Municipal heat planning is considered important to provide guidance to building owners and energy suppliers on which buildings would be served by either district heating or individual heating in the future. Denmark has a successful history of more than 40 years with this tool, and it was the basis for the very high share of both district heating and renewable energies in heating the country's homes and buildings.

With a revision of the municipal guideline, an impulse subsidy for municipal heat planning has been introduced as of November 1, 2022.

- In the new funding priority, the preparation of municipal heat plans by expert external service providers is funded.
- If applications are submitted by the end of 2023, the subsidy amounts to 90% of the total eligible expenditure; for financially weak municipalities and applicants from lignite regions, the subsidy amounts to 100%.
- After that, the grant rates are reduced to 60% and 80% respectively.
- The subsidy formulates content-related requirements for municipal heat planning, which are described in the Technical Annex to the Municipal Guidelines.
    - In addition to an analysis of the existing situation, the heating plan must also contain an energy and greenhouse gas balance, including a spatial representation.
    - This also includes a potential analysis to determine energy saving potentials or local potentials of renewable energies.
    - For two to three focus areas, which are to be prioritized in the short and medium term, concrete, spatially located implementation plans are also to be developed.
    - The participation of relevant administrative units, appropriate controlling and a continuation and communication strategy are also to be integrated into the planning.
- The federal government wants to legally obligate the states to have heat plans drawn up for a certain portion of the population and an associated space heating requirement (e.g. 75 percent).
    - A separate federal law will be created for this purpose, with different requirements depending on the density of the populated area.
    - For example, threshold values of 10,000 - 20,000 inhabitants are being discussed, above which municipal heat planning is to be implemented on a mandatory basis.
    - The federal states, which are obligated by the federal government, will transfer this task to the municipalities and districts.

- Methodological and content-related specifications as well as requirements are to be developed in parallel by the federal government together with the states, municipalities and stakeholders.
- So far, the following implementation steps are proposed for municipal heat planning:
    - Development of a heat plan (either by the municipality itself or by commissioning a service provider).
    - Public participation of the affected stakeholders (building owners, companies, energy suppliers, etc.)
    - Adoption of the heat plan as a legal act
    - Coordination of implementation
- In terms of content, four sections are mentioned in the preparation of the heat plan, which are to be spatially broken down for the entire municipal area:
    - The inventory analysis shows the current heat demand and the resulting GHG emissions, as well as information on building types, building age classes, and the current supply structure.
    - The potential analysis shows sinks (e.g. through renovation and an increase in energy efficiency) as well as potentials of renewable energies and waste heat.
    - In the target scenario, a climate-neutral target for heat supply in 2045 is shown, in which milestones for the years 2030, 2035 and 2040 also describe the future development of heat demand.
    - Finally, the heat transition strategy shows possible measures to achieve the goal of climate-neutral heat supply in 2045
- After the federal law for municipal heat planning comes into force, every obligated municipality should have drawn up a heat plan after three years at the latest.
- Municipalities in the "pioneer states" such as Baden-Württemberg, which have already drawn up a municipal heating plan, are to adapt their plans to the requirements of the federal law during this period - but there are not to be any major differences between previous and future requirements.
- Municipalities are entitled and obliged to collect and evaluate the necessary data from citizens, companies and other government agencies.
- The heat plans are to be updated every five years.

German Japanese Energy Transition Council

Roadmaps for climate-neutral petrochemical production systems

Comparative analysis for Germany and Japan

Wuppertal Institut

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List of Abbreviations, Units and Symbols

Abbreviations

#BEV	Battery electric vehicle
#BMBF	German Federal Ministry of Education and Research
#BMF	German Federal Ministry of Finance
#BMU	German Federal Ministry for the Environment, Nature Conservation, Building and Reactor Safety
#BMVI	German Federal Ministry of Transport and Digital Infrastructure
#BMWi	German Federal Ministry for Economic Affairs and Energy
#CCS	Carbon Capture and Storage
#CCU	Carbon Capture and Utilization
#CSP	Concentrated solar power
#DOE	United States Department of Energy
#EEA	European Environment Agency
#Fig.	Figure
#GDP	Gross domestic product
#GHG	Greenhouse gas
#GWP	Global warming potential
#ICT	Information and communication technology
#IEA	International Energy Agency
#IPCC	Intergovernmental Panel on Climate Change
#ISO	International Organization for Standardization
#LCA	Life-cycle assessment
#MAIA	Material intensity analysis
#Max	Maximum
#MiD	Mobility in Germany study
#Min	Minimum
#MIPS	Material input per service unit
#NECP	German Federal Government's Integrated National Energy and Climate Plan
#NPE	German National Platform for E-Mobility
#NRW	North Rhine-Westphalia
#OEM	Original equipment manufacturer
#R&D	Research and development
#REEs	Rare earth elements
#SMEs	Small and medium-sized companies
#Tab.	Table
#TCO	Total cost of ownership
#TMR	Total material requirement
#USGS	United States Geological Survey
#WI	Wuppertal Institut für Klima, Umwelt, Energie GmbH

Units and Symbols

#$	US dollar
#%	Per cent
#€	Euro
#°C	Degrees Celsius
#Ag	Silver
#Al	Aluminium
#Au	Gold
#bn	Billion
#CO_2	Carbon dioxide
#CO_2 eq.	Carbon dioxide equivalents
#Dy	Dysprosium
#g	Gram
#Gt	Giga tonne
#h	Hour
#H_2	Hydrogen
#H_2O	Water
#In	Indium
#kg	Kilogram
#km	Kilometre
#kt	Kiloton
#kW	Kilowatt
#kWh	Kilowatt hour
#l	Litre
#Li	Lithium
#m	Million
#MJ	Megajoule
#Mt	Metric tonne
#Nd	Neodymium
#Nm^3	Normal cubic metre
#p.a.	per annum
#pkm	Passenger kilometres
#ppm	Parts per million
#s	Second
#t	Tonne
#vol%	Percentage by volume

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1 Introduction

Germany and Japan have a great deal in common. The land areas of Germany and Japan are approximately 350,000 km2 and 370,000 km2, respectively. Nominal gross domestic product (GDP) is also very close (in 2022), with both Germany and Japan at about US$4 trillion. Another common point is that both the Germans and the Japanese have achieved an impressive recovery from the post-war economic crisis. In terms of population however, Germany's is only about 60% that of Japan, and although both countries share the social challenge of decreasing population, a comparison of GDP per capita shows that Germany's is about 30% higher than that of Japan at currency exchange rates.

Interestingly, the two countries also have very similar industrial structures. For example, both have a total of over 3.5 million companies, more than 90% of which are small and medium-sized enterprises (SMEs). And the manufacturing industry accounts for more than 20% of GDP in both countries. Both countries are also known for their automobile and machinery industries, which are key national industries in both Germany and Japan and important customers for the petrochemical industry as they enfold demand for products such as special engineering plastics like polycarbonate and polyamide or polyurethane foams, as well as coatings.

For both countries with this background, the petrochemical industry is indispensable in terms of economy and employment and has developed significantly as a key industry in the world. Hence, as various initiatives are carried out to achieve a carbon neutral society in the future, efforts to reduce CO_2 emissions in this sector play a very important role in achieving the policy goals of both countries. However, the emissions of the petrochemical industry itself (scope 1 and 2) are far less relevant than the end-of-life emissions of their products, which belong to scope 3 and are thus not necessarily totally counted in the countries' GHG accounts, as both countries are net exporters of raw polymers and products made of them (cars, machinery).

This paper therefore reviews the transformational challenge of the petrochemical industry in both Germany and Japan. Specifically, we review the social and geographical positioning and characteristics of the petrochemical industries in both countries (Chapter 2), and the status of policies and roadmaps in this area for CO_2 emission reduction (Chapter 3). And finally, based on the results of the analysis of the review of the petrochemical industry in both countries, the characteristics of the two countries are compared and discussed (Chapter 4). The report then summarized the research areas that Germany and Japan should prioritize in cooperation (issues to be resolved) and joint recommendations for reducing CO_2 emissions.

2 Industrial context

2.1 Germany

The petrochemical industry is one of the largest industries in Germany. With 350 000 people employed (VCI, 2022b), it produces a wide range of chemicals across all segments, including basic inorganics, petrochemicals, polymers, agrochemicals, specialties and cosmetics (Cefic, 2022a). Also globally, the German industry is one of the top players, especially as an exporter of chemical products. Indeed, among the world's chemical industries, the German is the third largest exporter and takes the fourth place in terms of sales, after China, USA and Japan (VCI, 2022a). The country is also host to the headquarters of several of the world's largest chemical companies, including BASF, Evonik Industries, and Covestro. At the same time, the industry has a large responsibility when it comes to its climate impact. In 2020, the chemical and pharmaceutical industry emitted 38.9 Mt CO_2-eq in direct emissions (VCI, 2022b), making up 5.3% of the Germany's total greenhouse gas emissions (UBA, 2022). Germany has set up the target of climate neutrality by 2045, and thus the industry faces a large challenge to mitigate these emissions and transform the industry.

2.1.1 Historical development

The structure of the German chemical industry has historical roots, some dating back as early as the 18th century. That was when the country's first fragrance producers settled in the Rhine region, and a chemical industry was then gradually built up in the region during the following century, making use of the local coal resources and by-products of coke production. Other clusters were also formed successively throughout Germany over the 19th and 20th century, in locations beneficial at the time. This can be for example close to coal resources, adjacent to other industries and in places with good connections to ports or land transport, and pipelines for energy and resources. Today, the industry can be said to be largely concentrated to six industrial clusters: Emscher-Lippe, Rheinland and Ludwigshafen along the Rhine River in the West, the North Sea (Nordsee), the Central German Chemical Network (Mitteldeutsches Chemiedreieck) in the East and the Bavarian cluster (Bayerisches Chemiedreieck) in the Southeast. Of the German clusters, Rheinland is the largest while the Bavarian and North Sea are comparatively small. The clusters have different characteristics, both with regards to what they produce, but also in terms of infrastructure connections and resource access, and thus dependencies.

2.1.2 German chemical industry today

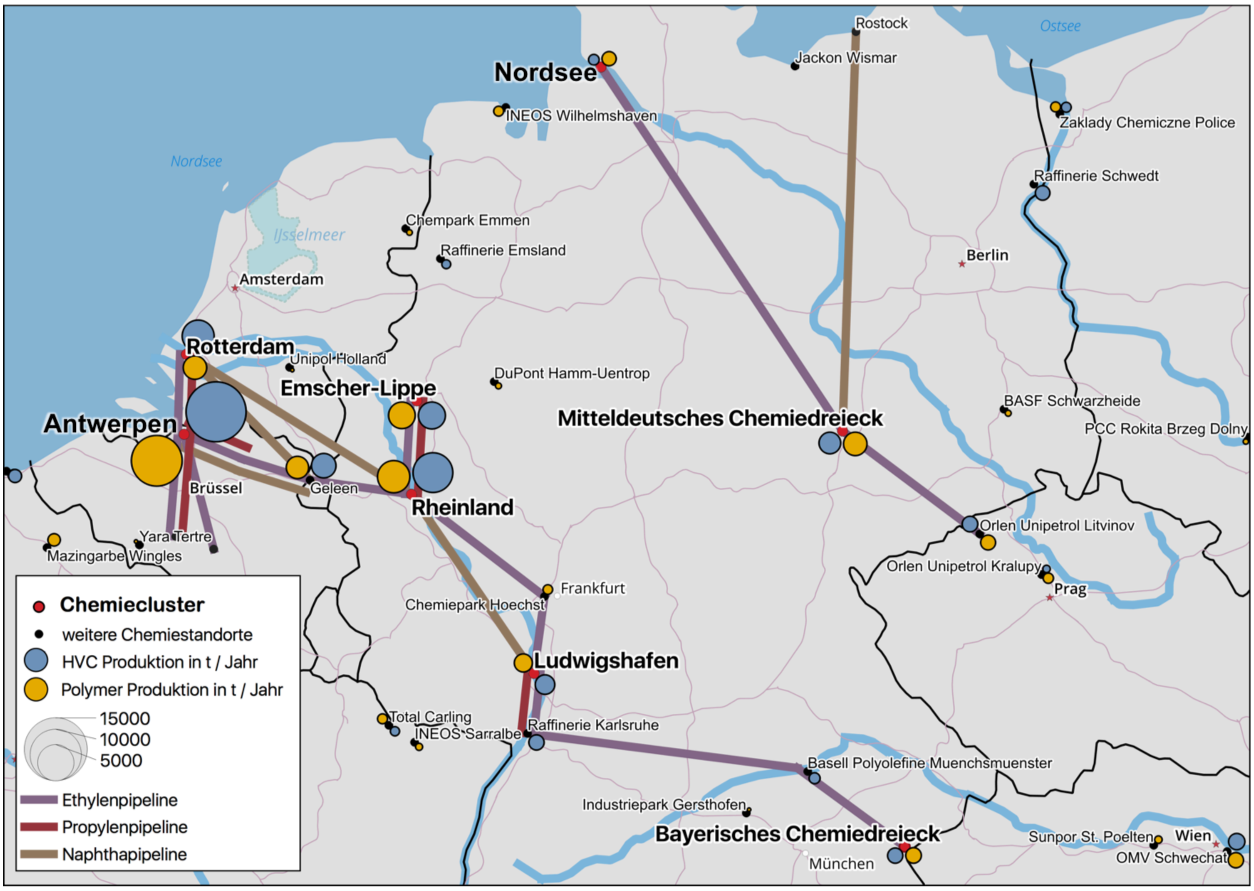


Figure 2-1 Petrochemical clusters in Germany and the Antwerp-Rotterdam-Amsterdam port area (ARA)

The German chemical industries have developed massively since their formation, not the least experiencing strong growth after World War II with the transformation from a coal- to an oil-based industry, and then later facing challenges as competition grew. It has thereby also become integrated in and dependent on the overall infrastructure and market system that it is now a part of. An example of this integration are the clusters Rheinland and Emscher-Lippe, which together with Antwerp in Belgium and Rotterdam in the Netherlands make up the superregional petrochemical cluster ARRRA (Antwerp-Rotterdam-Rhine-Ruhr-Area), integrated via oil and ethylene pipelines.

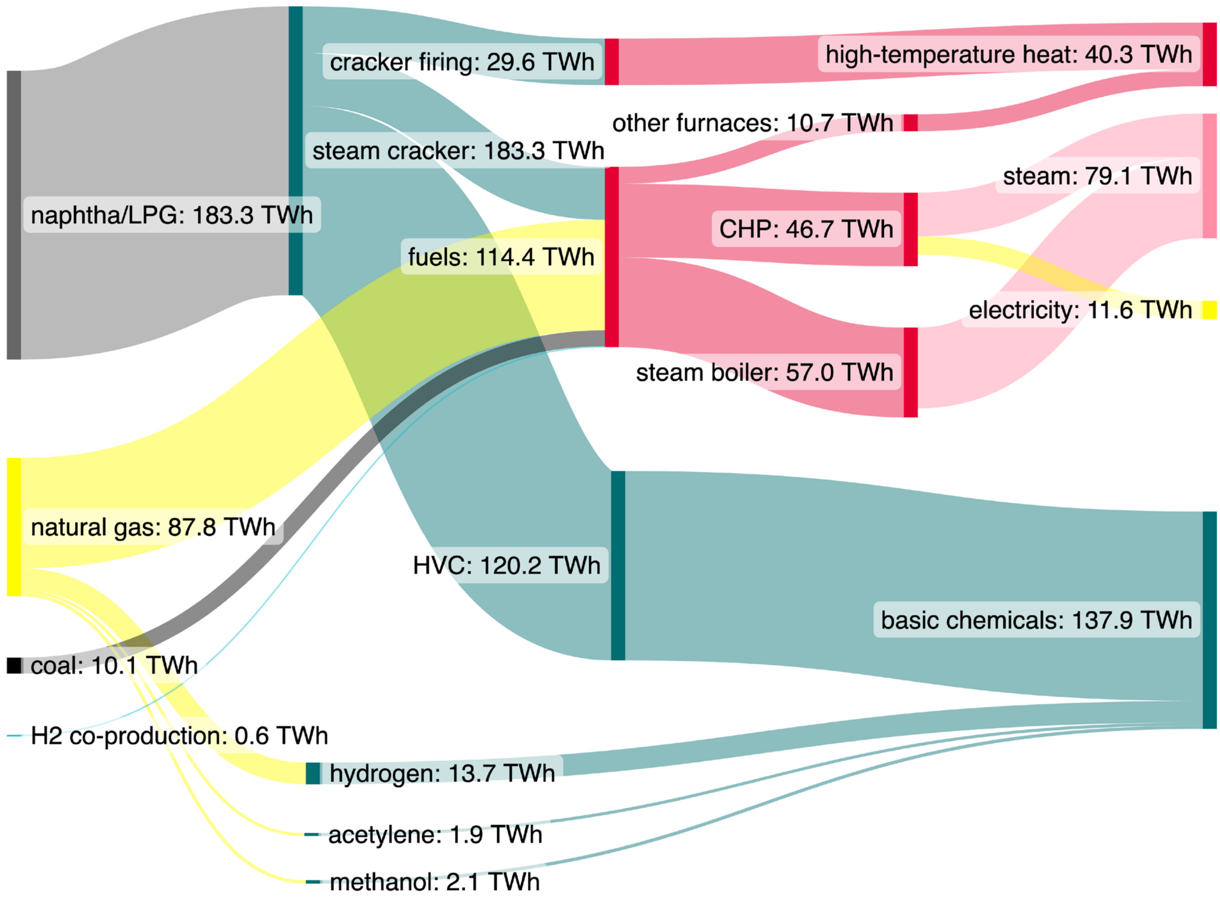


Figure 2-2 Sankey diagram for hydrocarbon energy flows in the German chemical industry

[source: model calculations of the Wuppertal Institut, Scholz et al. 2023]

Most of the clusters are also strongly integrated into the gas infrastructure and are dependent on the access to natural gas. While the oil-derivates naphtha and LPG clearly dominate primary energy supply, natural gas makes up 70% in BASF's Ludwigshafen site (Scholz et al. 2023). On the other hand, in the Rheinland and Bavarian cluster naphtha is the completely dominant energy carrier (> 90%). Dependencies also arise due to the structures within the cluster. For example, the plants in Emscher-Lippe and In Bavaria are very dependent on their respective refineries, and in the latter case the refinery does not even produce gasoline at all and instead provides more of the naphtha for the chemical industry. The various sizes of the clusters also affect their characteristics. Indeed, there is a large variation in sizes among the German clusters where the largest cluster Rheinland for example has an energy use ten times larger than the smallest cluster North Sea. The various integrations of the chemical clusters into the overall energy system, trade connections and structures mean that the different clusters have different challenges and opportunities when it comes to transforming them into net-zero GHG production.

2.1.3 Sustainability Agenda

Sustainability is high on the agenda in Germany, and the country has set a target to reach climate neutrality by 2045 for the country as a whole in its Climate Change Act (Klimaschutzgesetz), with intermediate sector targets for each year until 2030, and an overall intermediate target for 2040.

The chemical industry in Germany has also set the target to reach greenhouse gas neutrality by 2050 (Cefic, 2022a).

The required investments that would be needed to reach the targets in the sector would be very large and long-term, and require economic viability. This is especially important for an export dependent industry such as the German, which faces strong competition on a global market. The future is however very uncertain and the energy prices and framework conditions are still not where they need to be to fully enable an industrial transition in line with the targets. It is also unclear how the existing structures and dependencies affect the opportunities and challenges for transition. Can for example existing trade connections, cooperation structures and pipeline networks be used for leverage and help make the transition possible, or do they create an inertia that makes the challenge all the more daunting?

In any case, efforts towards more environmentally sustainable production are currently being made in several of the clusters and the companies, and some examples are summarized below. The focus is on chemical recycling and bio-based drop-in feedstock.

- In Ludwigshafen, there is an ongoing pilot project for chemical recycling via pyrolysis, and an upcoming partnership has been announced to deliver 18 000 t pyrolysis oil based on mixed post-consumer waste. Furthermore, smaller quantities of bio-naphtha and bio-methane are used, which in some cases are blended in with fossil raw materials, but in other cases used to produce 100% renewable materials. Also, an electric steam cracker oven line is planned to be constructed as a demonstration plant at the BASF site in 2023 (BASF 2022).
- The Rhineland cluster experiments with chemical recycling and production of biobased chemicals too. Pyrolysis oil is planned to be produced in the Netherlands by 2023, using in the scale of 30 t plastic waste. Some of the oil will then be transported and processed in the steam crackers in the Rhineland. Furthermore, Covestro is operating a pilot plant to chemically recycle polyurethane from used mattresses via chemolysis (Covestro 2021). Covestro and LyondelBasell are also partly using bio-sourced hydrocarbons for the production of polycarbonate respectively polyethylene and polypropylene (Covestro 2020, Packaging Journal 2019).
- The Central European Chemical Network is host to one bio-refinery, and another is currently being built which will be able to produce chemicals from hardwood. A pilot plant for chemical recycling of PET is also planned, and under construction is the largest PEM electrolysis plant for the production of hydrogen, as well as a hydrogen pipeline.
- In the Bavarian cluster, strategies are being set for relying more on sustainable polyolefins, where the plan is to produce 350 kt yearly by 2025 using for example recycled and bio-based solutions. Bio-based ethylene was produced in the steam cracker in 2021 for the first time, and collaborations are being established for chemical recycling (OMV 2022).

These ongoing and planned projects are however notably still just at the beginning and are yet very small scale compared to the conventional industry.

2.2 Japan

In Japan, the chemical industry has approximately 20,000 offices, 950,000 employees, and approximately 46 trillion yen in product shipments, which accounts for more than 10% of the total manufacturing industry. It is an important industry that supports Japan's economy and employment.

CO_2 emissions in FY2019 in Japan were approximately 1 billion tons. This amount represents about 3% of the world's total CO_2 emissions. Of this amount, the industrial sector accounts for more than 35% of Japan's total CO_2 emissions (about 380 million tons), and about 15% of the industrial sector's CO_2 emissions (about 56 million tons, or 5.4 % of the country's total CO_2 emissions) come from the chemical industry. It should be noted that the chemical industry emits not only CO_2 from energy sources (electricity, heat, steam, etc.), but also emits from the use of raw materials such as naphtha. Japan aims to achieve a carbon-neutral society by 2050. Therefore, CO_2 emissions from the chemical industry cannot be ignored in achieving this goal, and its reduction is an urgent issue that requires a major social reform of the entire energy system.

Japan is an island nation surrounded by the sea and is not rich in underground resources. In the past, Japan also mined coal, but as imports of cheap energy resources from overseas have expanded, the supply of domestic energy resources has gradually shrunk, and is now almost non-existent. Not many reserves of natural gas or oil have been identified. In addition, with the rapid economic growth of the 1970s, energy consumption has increased rapidly. Today, Japan relies almost entirely on imports of energy resources from overseas.

For this reason, high-density energy needed to be imported to Japan in a highly efficient manner, and more than 50 years ago Japan became the first country in the world to successfully implement a project to liquefy and transport natural gas. It has been almost 55 years since a 30,000-ton LNG carrier from Alaska arrived in Japan in 1969. Marine transportation of natural gas by liquefied natural gas has now become a global standard.

Japan's energy self-sufficiency rate is about 12%. This figure is significantly lower than that of other developed countries, and is about 1/3 of Germany's self-sufficiency rate (about 35%). Japan's reliance on imports for energy resources is the reason why the Japanese chemical industry is concentrated along the coast and around ports. Figure 2-3 shows geographical locations of petrochemical complexes in Japan.

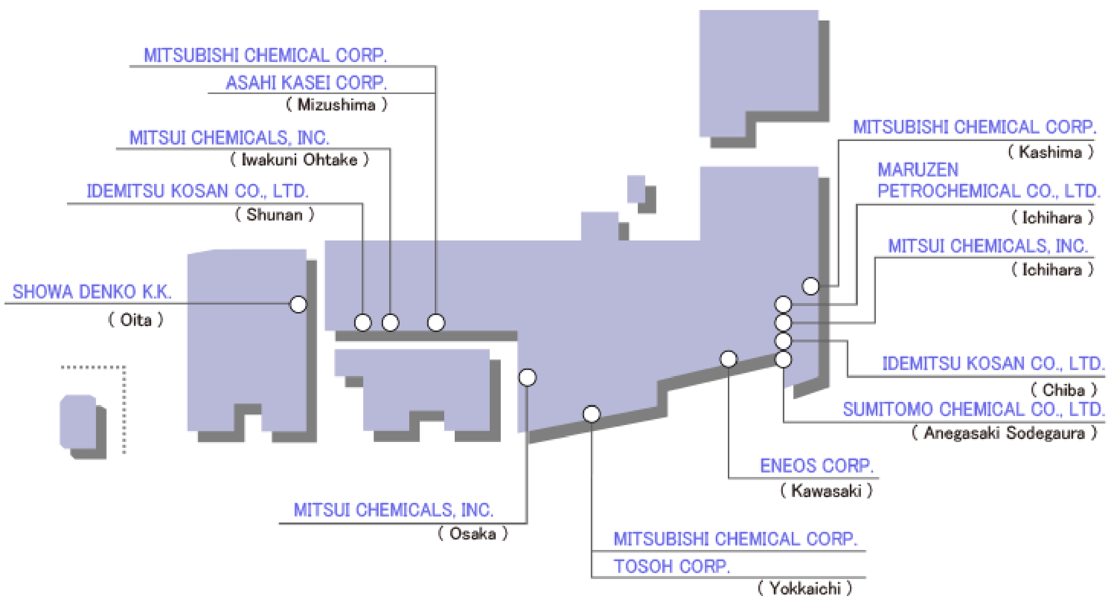


Figure 2-3 Geographical locations of petrochemical complexes in Japan

(Source: Japan Petrochemical Industry Association, https://www.jpca.or.jp/english/03petro_complex/index.htm)

Japan's first petrochemical complexes were built in Iwakuni and Ehime in 1958 to produce ethylene and polyethylene domestically. Since then, the petrochemical complexes have been efficiently producing petroleum, chemicals, electric power, and other diverse products in cooperation with each other by sharing facilities and other means with other industries.

Most of Japan's petrochemical companies are located in waterfront areas because of the convenience of shipping raw materials in and out of the country and the easy availability of land for land reclamation. On the other hand, the petroleum refining, chemical, steel, and power generation industries that make up the complex are also major emitters of greenhouse gases. Fuel such as green hydrogen, blue hydrogen, green ammonia, and blue ammonia, which are promising for decarbonization, are expected to be imported mainly from overseas. Therefore, considering the storage and utilization of these fuels after importation, the location of the waterfront area will continue to be very important for implementing collaboration among companies at the port. As a result, studies are underway for the formation of a carbon neutral port (CNP) that will significantly reduce greenhouse gas emissions in the future by developing the ability to import large quantities of hydrogen and ammonia in a stable and inexpensive manner.

Japan relies almost entirely on imports of primary energy from overseas, amounting to about 17,000 PJ of energy as shown in Figure 2-4 Fossil resources and fossil fuels (oil, coal, and natural gas) account for about 90% of primary energy, which is a source of CO2 emissions. Of this primary energy, about 7,300 PJ (about 43%) is consumed in power generation, of which fossil fuels account for about 80% (about 5% oil, 37% coal, and 37% natural gas). From the approximately 7,300 PJ of energy, about 3,300 PJ is supplied as electricity to the industrial, transportation, and consumer sectors. The other 9,700 PJ of energy not used for power generation is consumed as raw materials and fuels in the industrial, transportation, and consumer sectors. The energy consumed in the industrial sector is about 3,146 PJ, accounting for about 18% of primary energy.

Furthermore, about 747 PJ of energy is consumed in the chemical and petrochemical sector in the industrial sector as shown in Figure 2-5. Energy consumption in the chemical and petrochemical sector consists of about 45% oil, 17% coal, 11% natural gas, and 26% electricity. As you have probably figured out by now, even if all the electricity consumed in the chemical and petrochemical sector were covered by renewable energy, it would only amount to about 26% (about 191 PJ) of the total.

The remaining energy comes from fossil fuels, and unless we recognize this and take some measures, we will not be able to achieve a fundamental reduction in CO2 emissions. In other words, energy equivalent to the consumption of oil, coal, and natural gas must be replaced by CO2-free raw materials and fuels.

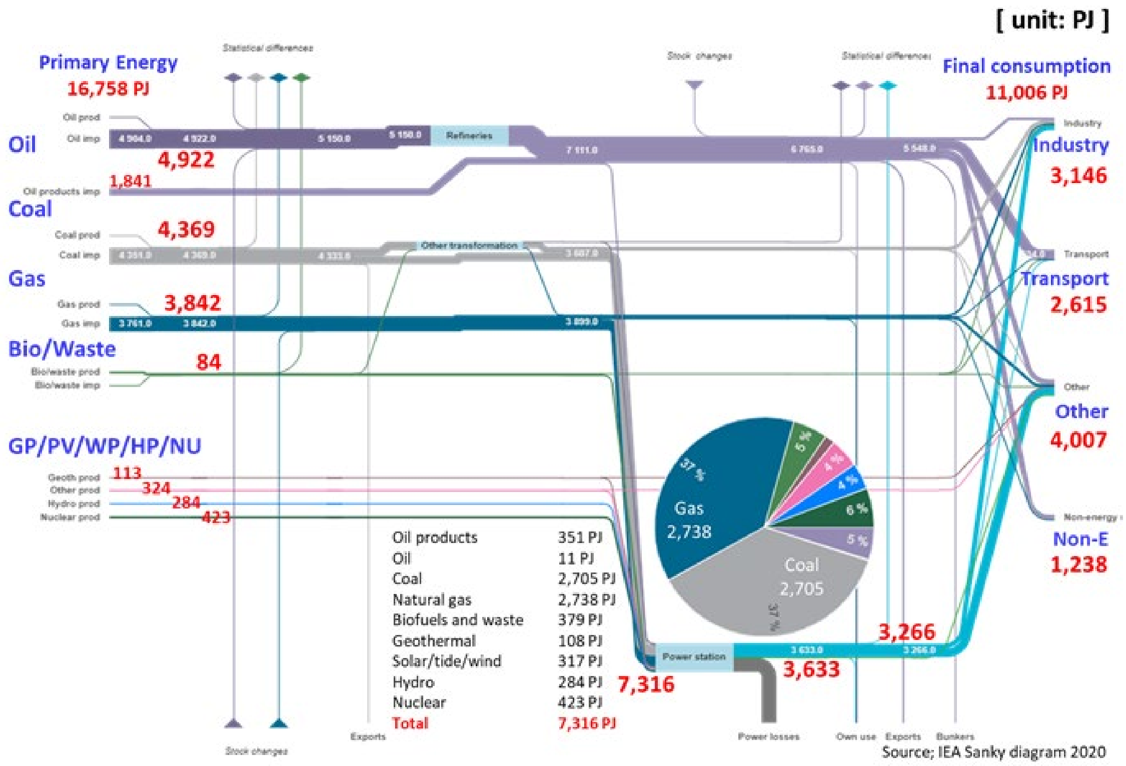


Figure 2-4 Energy consumption in Japan

(Source: IEA Sanky Diagram 2020)

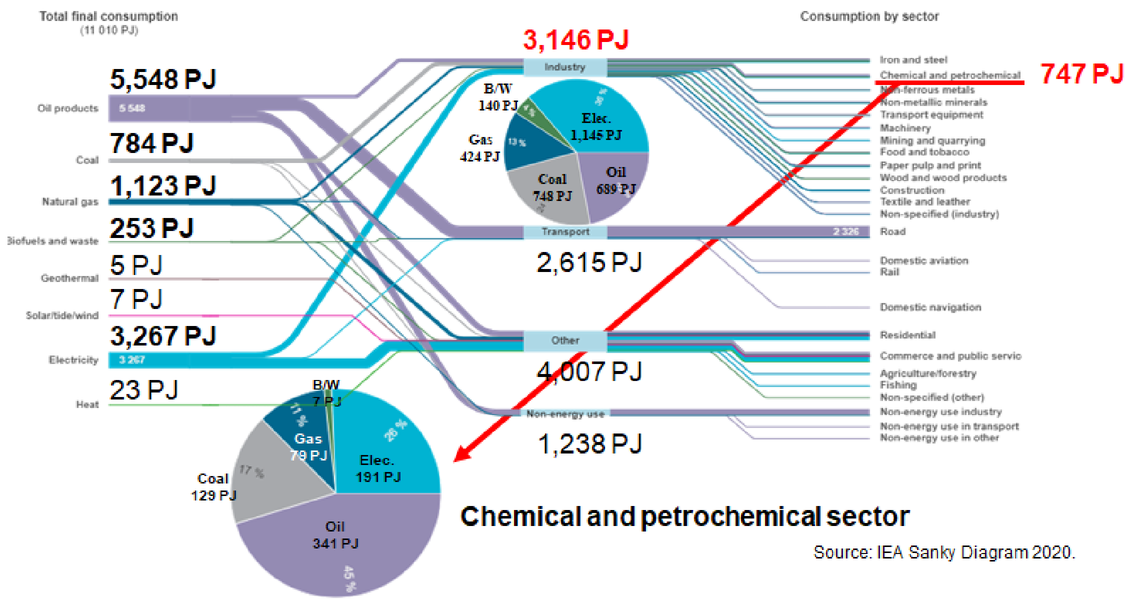


Figure 2-5 Energy consumption in chemical and petrochemical sector

(Source: IEA Sanky Diagram 2020)

3 Scenarios and roadmaps for decarbonizing the chemical industry in Germany and Japan

3.1 Study selection criteria

With the goal of capturing the currently ongoing debate among major stakeholders in the respective countries, the following criteria were set up for the selection of studies to include:

- National focus: Focused on Germany and Japan respectively.
- Sectoral focus: Covering the chemical and/or petrochemical industry in terms of energy and feedstock. Studies may have a broader industrial scope, but should contain sections addressing the chemical industry specifically. Furthermore, studies with a focus on steam generation at chemical or petrochemical parks are considered relevant as well.
- Major stakeholder involvement: Commissioned by trade associations, trade unions or government agencies/ministries.
- Recent: Published earliest 2018

Thus, for example studies with a wider geographical scope (such as Global or European), too limited or too unspecific sectoral scope (e.g., focusing on ammonia only or aggregating all of industry), purely academic studies and older studies were not selected. Based on these criteria, six studies for Germany and five studies for Japan were chosen, as presented in Table 3-1 and 2, respectively.

Table 3-1 The selected studies for Germany.

Code	Title	Made by	Commissioner	Year
RoadChem	Roadmap Chemie 2050 Auf dem Weg zu einer treibhausgasneutralen chemischen Industrie in Deutschland	Dechema and FutureCamp	VCI	2019
Wege	Wege in eine ressourcenschonende Treibhausgasneutralität	UBA	-	2019
DenaLeit	dena-Leitstudie – Aufbruch Klimaneutralität	EWI	dena	2021
KlimaPfade	KLIMAPFADE 2.0 Ein Wirtschaftsprogramm für Klima und Zukunft	BCG	BDI	2021
Langfrist	Langfristszenarien für die Transformation des Energiesystems in Deutschland 3	Consentec, Fraunhofer ISI, ifeu, TU Berlin	BMWi	2021
DeAufWeg	Deutschland auf dem Weg zur Klimaneutralität 2045 Szenarien und Pfade im Modellvergleich	Kopernikus-Projekt Ariadne and Potsdam-Institut für Klimafolgenforschung (PIK)	BMBF	2021

Table 3-2 The selected studies for Japan.

Title	Made by	Year
Energy Saving Technology Strategy	METI and NEDO	2019
The Sixth Basic Energy Plan and Long-Term Energy Supply and Demand Outlook	METI	2021
Roadmap for Carbon Recycling Technologies	METI	2021
Green Growth Strategies Associated with 2050 Carbon Neutrality	METI	2021
Keidanren Carbon Neutrality Action Plan **-- Vision toward Carbon Neutrality by 2050 and Fiscal 2021 Follow-up Results (Performance in Fiscal 2020) --**	KEIDANREN (Japan Business Federation)	2022

Note: METI = Ministry of Economy, Trade and Industry, Japan, NEDO = New Energy and Industrial Technology Development Organization, Japan.

3.2 Germany

3.2.1 Analysis of roadmaps

The six chosen roadmaps for Germany are here presented in short, including who made or commissioned the roadmap, the type of study, ambition level and the role of the chemical sector in the roadmap. They are then summarized and compared in terms of (i) strategies and technologies to reduce emissions, both with regards to feedstock and energy, (ii) timeline for the emission reduction and strategies, and (iii) major challenges identified and policy recommendations.

3.2.1.1 Overview of roadmaps

In Germany, several documents with modelled scenarios have been developed for the energy system as a whole. These are often commissioned by government agencies including those concerned with energy, economic affairs, education, and environment. Apart from these, a similar report has been published by the Federation of German Industries (BDI). All of these take a broad approach to drawing out possible pathways for Germany to become carbon neutral by 2045, concerning all major sectors. In them, the chemical industry is considered as a part of the industry sector, for which some specific results are also presented. In contrast to this, the German chemical industry's business association has developed a roadmap specifically focused on the chemical industry. For the assessment of the German discussion on chemical industry defossilization, all these documents have been included, and a brief presentation of each is given below.

Roadmap Chemie 2050 Auf dem Weg zu einer treibhausgasneutralen chemischen Industrie in Deutschland (by Dechema and FutureCamp for VCI)(Roland Geres et al., 2019)

The roadmap written for the German chemical industry association (VCI) investigates a possible path for transformation, measures, technologies and investments needed, and how far towards carbon neutrality the industry can progress. As such, it hopes to provide a structure to discussions from a technical perspective, to enable conclusions and focus points. Two pathways with different ambition levels are modelled, as well as a reference pathway. The first pathway named "Technology pathway", reaches 61% emission reduction from the sector by 2050 compared to 2020, while the second named "Greenhouse gas neutrality pathway" reaches 97% emission reduction. Unlike the other documents, this roadmap focuses solely on the chemical sector.

dena-Leitstudie – Aufbruch Klimaneutralität (by EWI for dena)(Deutsche Energie-Agentur GmbH (Hrsg.), 2021)

The German Energy Agency (dena) presents one scenario for carbon neutrality (KN100) by 2045 for the German overall system in this document, with a focus on energy sources and their required quantities. It describes an integrated energy system and society, with more detailed analysis of the building, industry, transport, and energy sectors. Furthermore, the report explores aspects like market design, innovation, societal anchoring, and the international interplay. For each chapter, central recommendations for action are presented for the coming legislative period. The chemical industry is modelled as part of the industry, and is discussed in broad terms.

KLIMAPFADE 2.0 Ein Wirtschaftsprogramm für Klima und Zukunft (by BCG for BDI)(BCG, 2021)

Since the first version named Klimapfade für Deutschland was made in 2018, the German government updated and tightened its climate targets. In this second version of the climate path, these updates have been taken into account. Commissioned by the federation of German industries (BDI), the study aims to formulate climate policy instruments that enable all sectors to reach the set targets for 2030 and greenhouse gas neutrality by 2045. In it, one path to climate neutrality for Germany is modelled and explored with regards to industry, transport, energy supply, and buildings, and for each of these, recommendations for policy instruments are given. The study also discusses investments and costs as well as policy issues in greater detail. For the industry sector, the basic chemical industry is one of the three parts particularly considered, alongside steel and building materials.

Langfristszenarien für die Transformation des Energiesystems in Deutschland 3 (by Consentec, Fraunhofer ISI, ifeu, TU Berlin for BMWi)(Fleiter et al., 2021)

In this project, a future greenhouse gas neutral system by 2050 has been modelled on behalf of the German Federal Ministry for Economic Affairs and Energy (BMWi). Rather than showing one main scenario, it investigates and compares three future scenarios relying with priority on one energy source each: electricity, hydrogen and PtG/PtL respectively. Thus, advantages and disadvantages of the different paths are made clearer, and path dependencies respectively robust developments are identified. In the project, different parts of the energy system are reported in different modules, one of which is the industry sector. In the industry module, basic chemistry, iron and steel, as well as the cement and lime sector are modelled. The system has also been modelled with a particularly high regional granularity, allowing for analysis of regional differences and the varying effects and on regions with different characteristics.

Deutschland auf dem Weg zur Klimaneutralität 2045 Szenarien und Pfade im Modellvergleich (by Kopernikus-Projekt Ariadne and Potsdam-Institut für Klimafolgenforschung (PIK) for BMBF)(Kopernikus-Projekt Ariadne, 2021)

Made with support of the German Federal Ministry of Education and Research (BMBF), this project integrates six overall system and sector models to build scenarios for Germany's transition path to climate neutrality by 2045. In total, six scenarios are modelled for the whole system: Electrification (domestic), Electrification (import), Hydrogen (domestic), Hydrogen (import), E-fuels as well as a final Technology mix. The report presents sections for industry, transport, buildings, and energy supply. Additionally, the role of hydrogen and e-fuels is also elaborated on, as well as sector interactions and sector coupling. Policy recommendations are also given for each section. The chemical industry is briefly discussed, but no quantitative results are presented. However, the model used for the industry sector is the same as in the Langfristszenarien report described above.

Wege in eine ressourcenschonende Treibhausgasneutralität (by UBA)(Purr et al., 2019)

This study, made by and for the German Federal Environment Agency (UBA), has a specific focus on resource conservation in addition to emission reduction. Six scenarios until 2050 have been produced: GreenEe1, GreenEe2, GreenLate, GreenMe, GreenLife, and GreenSupreme, describing a Germany with at least 95% reduction of emissions by 2050 compared to 1990. In line with the focus on resource conservation, the analysis considers lifestyle changes, and the scenarios avoid CCS and limit the use of biomass. It discusses effects in terms of greenhouse gas emissions, raw material consumption and global effects. In addition to the sectors covered also in the other reports (i.e., energy supply, building, mobility, and industry) this report also includes chapters on the waste and waste water sectors as well as agriculture and land use. Similarly to the previously described reports, the chemical industry is modelled and discussed in broad terms as a section of industry, as one of nine other industries.

Company initiatives

The roadmaps described above do not necessarily reflect planned efforts by chemical companies on the ground, where indeed several companies active in Germany have also set up targets to reach net-zero emissions by 2050. This includes BASF, Dow, Sabic, Ineos, LyondellBasell Industries, DuPont and more recently Covestro, who has set the target of climate neutrality by 2035. In most of these cases, this refers to scope 1 and 2 emissions, although this is not always clearly defined. Dow furthermore includes scope 3 emissions and product benefits in their carbon neutrality target. However, of these, only BASF and Covestro have published some kind of quantitative roadmap for how these targets are to be reached, and LyondellBasell industries similarly shows this in their sustainability report. These roadmaps are however not as detailed as the other roadmaps included in this report, and will therefore only be briefly summarized here. The focus for reducing emissions in the company roadmaps is primarily on the energy-related emissions, as described below:

- The BASF roadmap presentation *Our journey to net-zero emissions 2050* (BASF, 2021) contains indications of which strategies are to be used to reach 25% emission reduction by 2030 compared to 2018. The path from 2030 to 2050 is not specified. More than half of the reduction until 2030 will be due to renewable electricity and heat electrification measures. The use of new technologies like electric steam cracking, water electrolysis, methane pyrolysis and CCS make up about 20% of the reduction. Optimizations and emissions offsetting make up the remaining emission reduction. The use of bio-based feedstock plays a very marginal role.
- The 2021 sustainability report of LyondellBasell Industries (LyondellBasell, 2022) presents an emission reduction of 30% until 2030 compared to 2020. Here, planned greenhouse gas reduction projects such as minimizing flaring, fuel switches and energy use optimizations make up about half of the emission reduction. Renewable electricity makes up about 20% of the reduction and the rest is not specified.
- Covestro presents their planned emission reduction in their presentation *We Will Be Fully Circular* (Covestro, 2022). A 60% emission reduction is to be achieved until 2030, consisting of 40% renewable electricity, 30% renewable steam and 30% more sustainable manufacturing. The remaining emissions are reduced until 2035 in a similar pattern. More sustainable

manufacturing here refers to the use of catalysts to reduce nitrous oxide emissions, energy optimizations and more digitalization for more efficient production control.

3.2.1.2 Strategies for feedstock

In the selected roadmaps, the overall production volumes in Germany are expected to remain stable or decrease by up to 40% until the target year, with an exception for specialty chemicals in *RoadChem* which are there expected to increase by 2% per year in value. To supply the feedstock needed, all available options for feedstock defossilization are used in the roadmaps, i.e., recycled feedstock, biomass-based feedstock as well as feedstock based on captured CO2, as can be seen in (BCG, 2021). Especially for CO2-based production, the addition of hydrogen is required. Some fossil feedstock is assumed to remain in some of the scenarios. Often, the strategies are used in combination, although routes based on captured CO2 and hydrogen tend to dominate in the German scenarios.

Table 3-3 Feedstock used in the pathways, as shares of total feedstock base for the products specified in the roadmaps.

Roadmap	Scenario	Fossil	Recycling	Biomass	CO2 and H2
Wege	(All scenarios)	0%	nq	22%	78%**
RoadChem	Technology pathway	46%	12%	29%	14%
	GHG neutrality pathway	6%	11%	28%	55%
KlimaPfade	Proposed path	0%	30%*	0%?	70%
Langfrist	TN-Strom	0%	nq	0%	100%
	TN-H2	0%	nq	0%	100%
	TN-PtG/PtL	0%	nq	0%	100%
DenaLeit	KN100	19%	nq	9%	72%

Notes on the table:

A deeper colour corresponds to a larger share and yellow is used if the feedstock source is mentioned but not quantified.

* 18% mechanical recycling, 12% chemical recycling.

** Other renewable than bio-based is not further specified in the report and subsumed here under CO2/H2.

Recycled feedstock is generally considered an important part of a future circular economy, although not always quantified as part of the feedstock as recycling is considered separate from the chemical industry. All roadmaps refer to increased mechanical recycling, collection rates or material efficiency. Furthermore, RoadChem and KlimaPfade explicitly point to chemical recycling in the form of pyrolysis or a mix of pyrolysis and gasification. Recycled feedstock represents 10 to 30% of the feedstock in the cases where it is explicitly considered.

The use of biomass for feedstock is mixed, ranging from 9 to 30% of feedstock but also 0% in other scenarios, and 40% of the methanol in DenaLeit. It can also be difficult to distinguish its use from CCU, since the carbon source in platform chemicals is sometimes lumped together, or BECCU is used. In the two cases where it is quantified, the technology used is gasification.

The main source of carbon used in all of the German roadmaps is CO2. In total, captured carbon makes up 14 to at least 72% of the feedstock used, or 55-72% when only net-zero scenarios are considered (mechanical recycling is in most cases not counted here). The CO2 is most often sourced from air, but industrial sources are also often used, including waste incinerators and district heating as well as the cement industry. Some of the roadmaps (Wege and KlimaPfade) also open up for capture from fossil sources, at least temporarily. The feedstock is in many cases assumed to be imported in the form of synthetic naphtha or methanol from places with presumably better access to cheap renewable electricity. The origin of the carbon is then not always clear, although DenaLeit states that DAC is the preferred. As CO2 contains no energy, hydrogen must be added, and large amounts of renewable electricity are needed to produce carbon neutral hydrogen through water electrolysis. While green hydrogen production through water electrolysis is the most common technology assumed, methane pyrolysis and steam methane reforming (SMR) hydrogen production equipped with carbon capture are part of one roadmap each.

The subsequent production processes of feedstocks into hydrocarbons are partly independent from the feedstock. The most common routes assumed are to either make methanol, which can then be turned into a variety of chemicals via MtO or MtA routes, or to produce synthetic naphtha by turning the feedstock into syngas by the addition of H2 and using it in Fischer-Tropsch (FT) plants. The synthetic naphtha, which is one target product of the FT processes next to hydrocarbon fuels like kerosene is then used in conventional steam crackers. The route with synthetic naphtha thus allows for the continued use of available plants and infrastructure.

3.2.1.3 Strategies for electricity, heat and steam

Most roadmaps foresee a reduction in energy demand from the chemical sector, down to a 35% reduction in the *TN-Strom* scenario in *Langfrist* (there referring to final energy use only), but it may depend on whether e-fuels are counted in terms of energy content or electricity needed for production. Only *RoadChem* includes electricity needed for the production of hydrogen, and presents energy both for final energy use and for feedstock, and projects a 87% increase in this energy demand. Most of the energy demand in the chemical industry is assumed to be supplied in the form of electricity, as can be seen in Table 3-4, which presents the energy sources used for power and heat. The electricity is modelled to be fully renewable by 2045 in order to be in line with the German emission goals, and is then almost exclusively produced via on- and offshore wind as well as solar PV. Electrification of chemical industry processes is described through the use of heat pumps, electrified boilers, furnaces (including in some cases steam crackers). While electricity is the main source of energy in all scenarios except one (which focuses on PtG/PtL), this is supplemented by smaller shares of biomass or biogas, or electric fuels (i.e., hydrogen and synfuels). The fuels that can be used depend on the temperatures required, where biogas, hydrogen or synfuels may be used for higher temperatures. Boilers may also be operated flexibly, able to accept a variety of fuels. For lower temperatures, district heating plays a role as well, contributing 5 to 10% of the energy demand. Apart from the defossilisation of fuels, all roadmaps also assume energy efficiency gains, for example through conversions to best available technologies (BAT).

The energetic use of hydrocarbon by-products, which is today a very important source (see Figure 2) may shrink due to increased carbon recycling at the sites, but its potential future role is in general hardly addressed by the studies.

Table 3-4 Energy sources used for non-feedstock purposes in the scenarios, as shares of total non-feedstock energy use.

Roadmap	Scenario	Fossil	Waste material	Biomass	H2	Electricity	Other/Non-separable
Wege	GreenLate	0%	nq	0%	nq	82%	18%
	Other scenarios	0%	nq	0%	nq	74%	26%
KlimaPfade	Proposed path	0%	2%	11%	2%	76%	8%
Langfrist	TN-Strom	1%	0%	0%	0%	88%	12%
	TN-H2	1%	0%	0%	29%	60%	11%
	TN-PtG/PtL	0%	0%	0%	0%	34%	66%
DenaLeit	KN100	5%	0%	17%	16%	50%	12%

Notes on the table: A deeper colour corresponds to a larger share. Yellow is used if the energy source is mentioned but not quantified ("nq"). Hydrogen and synthetic fuels are in all cases counted in terms of the fuels energy content.

3.2.1.4 Timelines

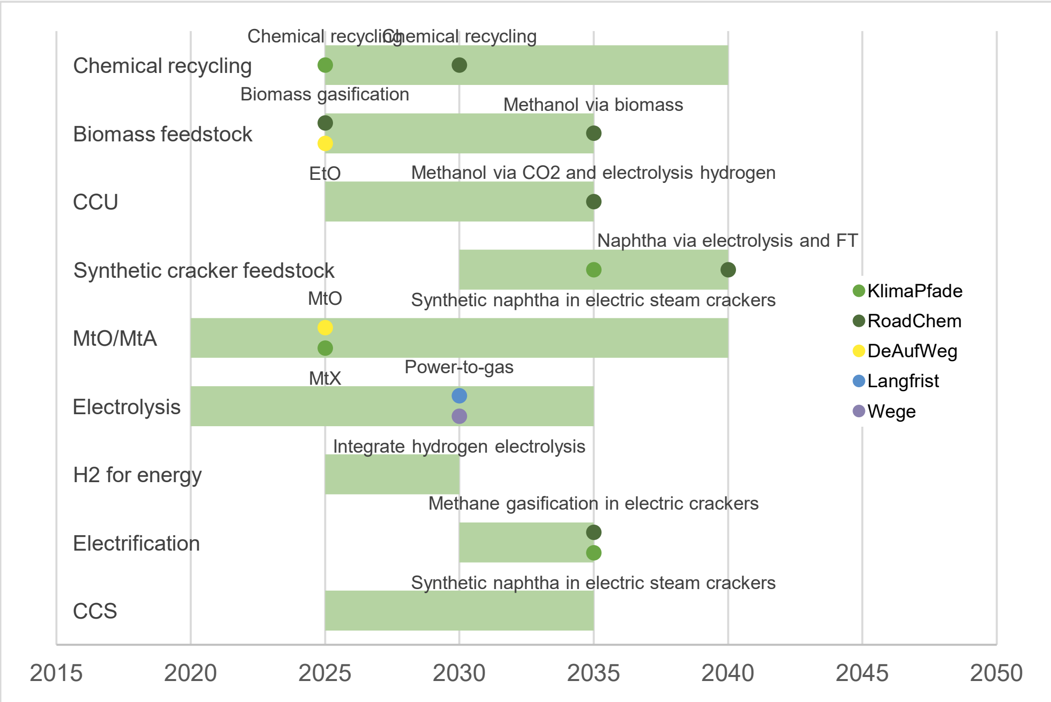
A central question in the discussion is timing. When could potentially the technologies be available, the necessary infrastructure be in place? When are which investments needed? When then can the new technologies start to contribute significantly to production, the emissions significantly decrease and reach net-zero? While some indications of possible timelines are given in the roadmaps (see Fig. 3-1 and Fig. 3-2), the questions around when things can happen depend on external factors as well, and still remain partly open.

The clearest indications for timing given in the roadmaps concerns when technologies are assumed to be available (Figure 3-1). The roadmaps indicate that the period around 2025 to 2035 will be a time when many technologies come into use in general, and by 2040 all the technologies are expected to be available. For specific technologies or strategies, the assumptions are spread, especially when more roadmaps outside the scope of this report are considered (indicated by the green bars in Fig. 3-1). It can be noted that none of the German roadmaps give an indication of when hydrogen could be used for energy purposes, or when CCS may come into use in the chemical industry. The availability of these options is not about TRL but about related infrastructure needs, that have to be built up. So their phase-in is highly driven by the duration of public planning processes. Furthermore, the production of hydrogen via methane pyrolysis ("turquoise hydrogen") was only indicated in RoadChem, for 2040. Following the market introduction of the technologies, a rapid scale-up is needed, i.e., 10 to 15 years in order to be able to reduce emissions to net-zero by 2045. Indeed, the emissions are modelled to decrease more rapidly after 2035 in several scenarios, even though some also foresee a linear decrease.

As for the development of emissions, the roadmaps portray a linear decrease towards net-zero, or a slower initial decrease followed by an accelerating decrease (see Figure 3-2).

The federal law on climate protection foresees a reduction of scope 1 emissions in the total industry sector by 37% until 2030 compared to 2015. Only in the most ambitious pathways displayed, the chemical industry would deliver an equivalent share, in the other pathways other industrial sectors would have to compensate for the slow start of the chemical sector towards decarbonization.

In the German context of Energiewende, there are also intermediate targets set for the energy system, including the phase out of coal until 2038, and a target of 80% renewable electricity by 2030 (compared to 46% today) (Die Bundesregierung, 2023). Achieving these targets will lead to reduced scope 2 emissions for the industry until the next decade.



The bars represent the span for when technologies of the given category come into play based on a wider selection of roadmaps (e.g., not only with a German scope).

Figure 3-1 Timeline indications for key technologies given in the German roadmaps (points).

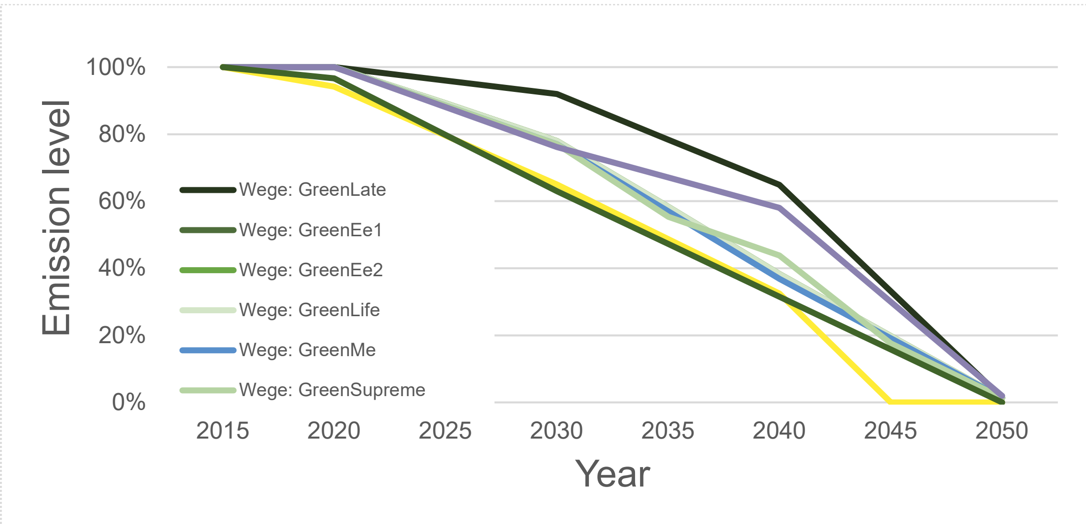


Figure 3-2 Emission development in the German scenarios.

3.2.1.5 Challenges identified in roadmaps

The transformation of the chemical industry, which is currently completely dependent on fossil resources both for energy and feedstock, is recognized as a large undertaking in the German roadmaps, and the speed needed to reach the goals until 2045 brings the challenge to a head.

A transformation to a climate neutral chemical industry is naturally associated with significant investment costs to convert all production and furthermore to build up the necessary infrastructure. To make the necessary investments into production units that are intended to be used for decades, the roadmaps suggest that the business case should be clear and with limited uncertainty, unlike today. Failure to reach a business case for a low-carbon chemical industry implies a risk of relocation, where industries move abroad to countries with better economic incentives for chemicals production, be it low-carbon or not. The roadmaps note some challenges in particular that must be overcome. These concern especially investments, price signals, competitiveness, infrastructure, and uncertainties about future conditions. KlimaPfade and Langfrist for example point out that the price structures currently favor the use of natural gas over electricity for heat. The price for natural gas in Germany in 2030 is assumed in KlimaPfade to be 44-62 €/MWh, compared to 64-170 €/MWh for power-to-heat solutions. The range for natural gas price reflects dependency on the CO2 price, and the cost for power-to-heat is dependent on the user. RoadChem and KlimaPfade emphasize the challenge of transforming the electricity system, which is still far from delivering the required amounts of renewable electricity. They assume an electricity price of 40-50 and 64-174 €/MWh respectively, while the price today is 149 €/MWh (Statistisches Bundesamt (Destatis), 2022), when fossils still represent 47% of electricity production in Germany in 2021 (Eurostat, 2022). Furthermore, the necessary infrastructure for e.g., electricity, hydrogen and CO2 is not in place, which DeAufWeg, Langfrist and especially KlimaPfade describe. Such infrastructure must be rapidly expanded on a large scale, both on a national and European level. Uncertainties regarding local connections to these infrastructures also complicate planning. At the same time, the three mentioned roadmaps point to the finding that the price signal for CO2 is not strong enough on its own and not currently effective enough to make the low-carbon alternatives more affordable. DeAufWeg for example states that the CO2 price should be above 100 €/tCO2 in the medium term for CO2-neutral processes to be operated economically (although this is not specific for the chemical industry). All of this is seen to require simultaneously maintaining the competitiveness by providing support and subsidies for targeted investments. To conclude, the roadmaps point to their finding that the current framework does not sufficiently encourage a large-scale transformation and the long-term certainty needed is not in place.

3.2.1.6 Policy recommendations in roadmaps

Several recommendations for policy and government actions are presented to overcome the challenges and enable the described developments. Firstly, the direction of transformation can be set more clearly by government actors, and long term-commitment is needed. This comes for example in the shape of developing strategies for the use of resources like sustainable biomass, and planning infrastructure for e.g., electricity, hydrogen and CO2, as well as energy management and efficiency. There is also a strong emphasis on increasing resource efficiency and circular economy, for example through increased recycling targets and quotas for recycled input content. The direction would also be set clearly with a carbon price with a high steering effect. On the one hand, the price should be high enough to shift the balance in favor of low-carbon technologies, but on the other hand the industry should not be made uncompetitive, and competition should be fair between industries as well as countries. Some roadmaps argue that the EU ETS be expanded to sectors currently outside the system. At the moment, there are insufficient incentives through EU ETS to use or produce biopolymers.

Overall, the roadmaps call for increased and long-term engagement by governments in the industrial transition. This both through stronger coordination and enabling faster processes when it comes to planning and approval, but also through success control, monitoring and impact assessment of targets and regulatory frameworks. The transformation also requires long-term financial commitment and speed in technological development. Therefore, several documents also mention more targeted and focused support for technology development.

As long as industries in the EU face different requirements and costs than in other countries, the playing field is not levelled and unfair competition becomes an issue. Policy recommendations in the roadmaps are also directed at addressing this, and to ensure a business case for low-carbon technologies. As the electricity price is a main issue determining future economic viability, reducing this price is especially brought forward, where for example tax exemptions and changes to electricity levies are suggested, alongside the expansion of renewable electricity production. Green power purchase agreements (PPAs) are also promoted. Other tools often mentioned to counteract the business case imbalance of conventional technologies compared to low-carbon are carbon contracts for difference (CCfD) and green lead markets. CCfDs (i.e., contracts, in which the government agrees to pay a company for the difference between the cost of a carbon-neutral and the conventional technology, or at least between the emission abatement cost of a new technology and the market price for carbon) could be used for energy carriers for electricity, hydrogen, biomethane and products, especially up to 2030, but the framework around it would still need to be developed. Green lead markets can be used to create demand particularly for the low-carbon products. This can be in the form of quotas for low-carbon material inputs and of creating demand via public procurement. Finally, global harmonization is promoted, through the continued development of the carbon border adjustment mechanism (CBAM) and working harder for an internationally coordinated climate policy.

3.2.1.7 Outlook on discussions beyond the roadmaps

A large range of discussions and topics interplay with that of chemical industry defossilization, such as industry strategies, energy system and circular economy. Here we will elaborate on a few topics that are especially high on the agenda today and have a large impact on the situation in the chemical industry and its transition. These are: the ongoing energy crisis, shifts in the global playing field due to the Inflation Reduction Act in the USA, and developments regarding a hydrogen economy.

The ongoing energy and gas crisis in Europe due to Russia's invasion of Ukraine has put a strain on the European industries, and the German chemical industry not least. The energy prices in Europe have always been considered high compared to other world regions (but for natural gas lower in comparison to East Asia), and are now higher than ever. Furthermore as described above, many of the German clusters are highly dependent on natural gas. The chemicals and pharmaceuticals industry is responsible for 15% of Germany’s gas consumption and the German chemical industry has had a just under 50% reliance on Russian natural gas (Sabadus, 2023). The high gas and electricity prices have caused some chemical industry capacity to close, and the industry's margins are harmed by the volatile oil and feedstock prices. The fertilizer production, being very gas intensive, has been especially subject to capacity closures. The petrochemical industry is mainly dependent on natural gas for heat and electricity, but certain petrochemical products are also especially affected (Sabadus, 2023). Cefic released a position paper in October 2022 with regards to the energy crisis (Cefic, 2022b). In it, they highlight the trade deficit as the EU imports more chemicals than it exports, and call for action by the European Commission and Member States. They there ask for both emergency measures for the winter, and long-term measures for 2023 and beyond on the other. In November, the European Commission proposed a plan to accelerate renewables permitting processes as a measure to decrease dependence on Russian energy. At the end of 2022 (in particular in December), chemical production indices fell dramatically and BASF, being most hit by the high gas prices, announced additional plant closures in February 2023, including the permanent closure of one ammonia plant and the closure of a brand new TDI plant in Ludwigshafen. The recent decrease in the price of natural gas and oil (early 2023) has somewhat relived these strains, but the price is still higher than before the crisis. However, the price of electricity did not decrease as much yet, which has worsened the economic disincentives for electrification. The further direction that these energy prices take in the next years remains uncertain.

Another major point of discussion is the US Inflation Reduction Act, which was passed and signed into law in August 2022 (H.R.5376 - Inflation Reduction Act of 2022, 2022). This record size climate bill attempts to decrease the greenhouse gas emissions from the USA, avoid negative impacts on people due to climate change and the energy shift, while simultaneously making the USA and its industry into a green technology center globally (The White House, 2023). It is filled with subsidies and tax credits for a range of climate and energy related activities, including renewable electricity, manufacturing of clean vehicles, carbon removal, energy efficiency, clean hydrogen, and energy infrastructure in the USA (Boehm, 2023). Due to the global nature of the industry markets, such a bill affects the industries in Europe as well, and here high concerns have been raised by businesses and policy makers. Certain parts of the IRA law has been said to discriminate against European companies, unfairly tilting the global level playing field towards the USA at the expense of the EU, and fears of a trade war and a subsidy race have been voiced (Lee & Klevstrand, 2022; Reuters, 2022). The EU launched a task-force to address concerns by the EU regarding the IRA (European Commission, 2022a), and the EU has since required amendments. On the other hand, the director of Cefic has brought up the IRA as a model for the EU to emulate (Lopez, 2022). They point to the business case the IRA creates for green technologies in the USA, and that the EU ETS and CBAM are flawed and do not retain competitiveness in the EU. They also argue that the state aid rules should be revised to not prohibit subsidies and tax breaks, which the European Commission is now also considering (Kurmayer, 2022).

The crucial development of a hydrogen economy has seen some recent progress. On an EU level, rules have recently been proposed defining what should be counted as renewable hydrogen, in particularly clarifying in what way the electrolyzers must be connected to additional renewable electricity production, an how the hydrogen production should correlate to electricity production temporally and geographically (European Commission, 2023). There are also intensified international cooperations between the EU and other countries on this topic. A cooperation between the EU and Japan has been intensified, aimed at promoting innovation and the development of a global hydrogen market (European Commission, 2022c), and the presidents of the European Commission and Egypt have also issued a joint statement on an EU-Egypt cooperation on renewable hydrogen (European Commission, 2022b). Germany will be investing 550 million € into two hydrogen funds, that aim at fostering investments into hydrogen in developing and emerging economies, as well as accelerating a global green hydrogen infrastructure and market across all countries (BMWK, 2022).

3.2.2 Conclusions on German pathways

There are a variety of roadmaps for Germany tackling the defossilisation of the chemical industry. While the chemical industry is often not the main focus, it is an important part of the energy system as a whole. Based on the analysis of these roadmaps, a few conclusions can be drawn, but there are also many questions left unanswered.

The preferred strategy for defossilisation of the German chemical industry appears to be a mix of different feedstock and energy options, but there is an emphasis on CCU for feedstock and electricity for energy supply. As domestic resources of renewable energy and feedstock are limited, imports in terms of intermediate products and hydrogen play an important role. The German "industry business model" as a whole is dependent on global markets, and so is its industrial transition.

A priority in the German context is that the system should ideally not only be low-carbon, but also defossilized and renewable. This is true for the electricity, as well as the hydrogen, and means that for example nuclear power or blue hydrogen is often avoided in the roadmaps, due to the risks of nuclear energy and the residual GHG emissions from blue hydrogen. On a similar note, concern is given to the use of biomass by emphasizing that it must be sustainably sourced.

While there are several roadmaps pointing a way towards net-zero emissions for Germany, this does not imply that such a development is likely at current conditions. Rather, the documents intend to show what a development in line with the national and international targets could look like, but often emphasize the associated challenges and need for more action if it is going to be realized. The roadmaps are also filled with uncertainties and show deviating results, indicating that the path forward is all but clear for the involved actors and stakeholders. Such open questions include what the future market prices for electricity and other important resources will be, to what extent biomass could and should be used, how fast low-carbon technologies can be put into use and sufficient quantities of green hydrogen and PtX/PtL will be available in sufficient quantities at competitive costs, and consequently if and where low-carbon production can be competitive.

On top of it all, the German industries are currently experiencing several different fundamental movements due to world politics, both challenging and enabling. The vulnerabilities of the natural gas dependent industries have been made clear during the energy crisis, which has forced the natural gas dependent industry to large capacity closures. Also, the competitiveness for green production in the long term could be challenged by the new IRA law in the US, although at the same time, the IRA is sometimes seen as an opportunity to motivate political changes that enable a green transition of European industries. Furthermore, advances are being made to build up the necessary infrastructures and markets for low-carbon solutions, including a global hydrogen economy, and Germany and its industries are active players in these developments.

3.3 Japan

3.3.1 Analysis of roadmaps

This section provides a brief overview of the five strategies selected by Japan. The strategies related to the decarbonization of raw materials (feedstocks), electricity, and heat (steam), which are sources of CO2 emissions, are discussed. We then summarized their relationship to the timeline for the emission reduction and strategies, challenges identified in roadmaps, and outlook on discussion beyond the roadmaps from the perspective of policy recommendations.

3.3.1.1 Overview of roadmaps

(1) Energy Saving Technology Strategy (METI, 2019)

The first edition of the Energy Saving Technology Strategy was published by METI (Ministry of Economy, Trade and Industry, Japan) in April 2007. This strategy set a goal of "further improving energy consumption efficiency by at least 30% by 2030," and provided guidelines for specific directions to achieve this goal. Subsequently, the guidelines have been revised sequentially under the joint names of METI and NEDO (New Energy and Industrial Technology Development Organization, Japan), while reflecting government policies such as the Basic Energy Plan. Since there are so many energy conservation technologies in a wide range of fields, the guidelines identify priority fields and key technologies to be focused on to more effectively promote technology development.

In the 2019 revision, energy conservation technologies that lead to the use of waste heat and renewable energy as main power sources are identified as important technologies. Specifically, to promote the use of waste heat and the decarbonization of heat systems, technologies that convert waste heat into electricity with high efficiency and high-efficiency electric heating technologies are added to the list of important technologies. These technologies include high-efficiency power conversion of waste heat, circulating use of thermal energy, and high-efficiency electric heating (dielectric heating, laser heating, and heat pump heating).

In addition, based on the emergence of new business models that utilize digital technology and the rapid increase in the volume of information in recent years, technologies related to the 4th Industrial Revolution have been added to the list of important technologies. These include next-generation processors (neuromorphic and quantum computing), car and ride sharing, and blockchain.

Based on the policy of making renewable energy the main source of power, technologies related to the power supply and demand adjustment and reserve capacity have been added to the list of important technologies. These include grid-side/business and industrial high-efficiency power generation technologies that ensure flexibility, and the adjustment of electricity supply and demand (high-performance storage batteries).

Currently, a revision of the energy conservation strategy is under consideration based on the Sixth Basic Energy Plan announced in 2021.

(2) The Sixth Basic Energy Plan and Long-Term Energy Supply and Demand Outlook (METI, 2021)

The S+3E perspective is important in promoting energy policy. S+3E refers to the realization of a system that can supply energy stably (Energy Security) and at low cost (Economic Efficiency) on the premise of safety (Safety), and aims for environmental compatibility (Environment).

Based on this belief, the Sixth Basic Energy Plan was formulated on October 22nd, 2021, which sets the basic direction of energy policy. The year 2021, when this plan was formulated, marks exactly 10 years since the Great East Japan Earthquake and the accident at TEPCO's Fukushima Daiichi Nuclear Power Plant. The focus of this master plan is to chart a course for energy policy toward achieving "carbon neutrality by 2050," as announced in October 2020, and a new mid-term greenhouse gas (GHG) emission reduction target, as announced in April 2021. The new GHG emission reduction target is a 46% reduction in GHG emissions by 2030 compared to 2013 levels. The report also mentions that, in order to overcome the challenges posed by Japan's energy supply and demand structure while promoting climate change countermeasures, efforts will be made to ensure a stable supply and reduce energy costs, with safety as a major prerequisite.

And the Long-Term Energy Demand and Supply Outlook is a strategy released in conjunction with the Sixth Energy Basic Plan. It lays out a concrete path for a 46% reduction in GHG emissions. In other words, it shows how to overcome the various challenges that will arise in energy supply and demand as a result of attempts at thorough energy conservation and aggressive use of non-fossil energy, and what the structure of energy supply and demand will look like at that time.

According to the Long-Term Energy Supply and Demand Outlook, primary energy supply is expected to be about 430 million kL of crude oil equivalent (about 16,400 PJ), almost unchanged from the current situation. The breakdown is as follows: 31% oil (about 130 million kL, 5,000 PJ), 22-23% renewable energy (about 100 million kL, 3,800 PJ), 19% coal (about 80 million kL, 3,000 PJ), 18% natural gas (about 80 million kL, 3,000 PJ), 9-10% nuclear power (about 80 million kL, 3,000 PJ), 9-10% nuclear power (about 40 million kL, 1,500PJ), and 1% hydrogen/ammonia (about 2 million kL, 76 PJ).

(3) Roadmap for Carbon Recycling Technologies (METI, 2021)

CO2 is treated as a source of carbon, it will be utilized for producing chemical materials and fuels, mineralization source, etc. and it will also be able to control CO2 emissions. Carbon Recycling technology advances research and development of CO2 utilization promoting collaborations among industries, academia and governments around the world and stimulates disruptive innovation. The strategy outlines the direction of technology development for 2050 and beyond, and includes performance and cost targets for individual technologies.

This strategy was developed in June 2019, but was revised in July 2021 due to rapid progress in R&D aimed at international collaboration and the "Green Growth Strategy Associated with Carbon Neutrality in 2050," discussed below, which was developed in December 2020 and positions carbon recycling as a key technology for achieving carbon neutrality.

Specifically, DAC (technology for direct capture of CO2 from the atmosphere) and synthetic fuels (carbon-free decarbonized fuel produced by synthesizing CO2 and hydrogen), which have made remarkable progress, were newly added to the roadmap.

And until now, the roadmap had set "around 2030" for (1) those aiming for early deployment (those that do not need hydrogen or have high added value) and "around 2050" for (2) mid- to long-term deployment (general-purpose products). In the revised version, (2) above has been moved forward to "around 2040" in view of the progress and acceleration of development. In addition, the details of efforts for international collaboration, which has been progressing, have been added.

(4) Green Growth Strategies Associated with 2050 Carbon Neutrality (METI, 2021)

Achieving a carbon neutral society cannot be accomplished without extraordinary efforts. Therefore, in order to encourage innovation that encourages bold investment, the government has decided to allocate a generous budget to 14 selected areas that are expected to grow. No areas specific to the chemical industry have been selected, but technology development related to raw materials, electricity, and heat have been selected. The 14 areas include (1) renewable energy, (2) hydrogen and ammonia, (3) heat utilization, (4) nuclear power, (5) automobiles and storage batteries, (6) semiconductors and information and communications, (7) ships, (8) logistics, human flow and infrastructure, (9) food, agriculture, forestry and fisheries, (10) aircraft, (11) carbon recycling and materials, (12) housing, construction and power management, (13) resource recycling and (14) lifestyle.

(5) Keidanren Carbon Neutral Action Plan - Vision toward Carbon Neutrality by 2050 and Fiscal 2021 Follow-up Results (Performance in Fiscal 2020) – (Keidanren, 2022)

The Japan Business federation (Keidanren) consists of 1,494 representative Japanese companies, 108 major industry associations in the manufacturing and service sectors, and 47 local business organizations. They aim to develop the Japanese economy and improve people's lives by harnessing the vitality of companies and the individuals and communities that support them. They propose steady and prompt measures to address the various economic and industrial challenges facing the country, while compiling their views on the issues.

It also encourages domestic industries to formulate a vision (basic policy) for the realization of a carbon-neutral society in 2050. Therefore, they call for efforts to effectively reduce CO2 emissions through the maximum adoption of BAT (Best Available Technologies). Then, to achieve the goal of GHG emission reduction in 2030, the progress of each industry is surveyed every year, and the direction is reviewed and revised. The survey report is the Carbon Neutral Action Plan submitted by each industry section.

The Carbon Neutral Action Plan for the petrochemical (chemical industry) sector is compiled by the Japan Chemical Industry Association (JCIA) and reported to Keidanren. According to the JCIA, in its Carbon Neutral Action Plan for the Chemical Industry, the chemical industry section aims to reduce CO2 emissions by 6.79 million tons by 2030 on a fiscal 2013 basis. Furthermore, for 2050, the plan sets a goal of introducing innovative technologies to achieve carbon neutrality, such as technology to produce plastics from CO2, artificial photosynthesis, and positive use of biomass.

The JCIA has proposed its own LCA assessment index, cLCA (carbon life cycle analysis), for the treatment of CO2 emitted when chemical products are used by other industries or consumers. This method estimates the reduction in CO2 emissions by adding up the amount of CO2 emitted in each process of raw material extraction, manufacturing, distribution, use (consumption), and disposal, and comparing it to the amount of CO2 emissions if existing products were distributed. This concept will be applied not only in the chemical industry, but also in the fields of steel and cement as well as synthetic fuels in the future.

In May 2021, the JCIA published "The Chemical Industry's Stance Toward Carbon Neutrality”. It advocates rationalization of product manufacturing processes, introduction of innovative technologies such as electrification, fuel conversion for in-house power generation facilities, use of renewable energy, use of biomass, recycling of raw material carbon by utilizing waste plastics, process conversion leading to minimization of energy consumption, and development of new materials worthy of innovation in the entire value chain.

Like JCIA, in March 2021, the Petroleum Association of Japan (PAJ) released its "Vision (Aim) Toward Carbon Neutrality in the Petroleum Industry”. The industry is working on energy conservation measures, such as reducing energy consumption in heating furnaces by using high-efficiency heat exchangers, introducing advanced computerized control systems, and replacing steam turbines with high-efficiency motors as the power source for compressors. Toward 2050, the company is also working to develop innovative technologies, such as promoting the recycling of waste cooking oil and waste plastics, utilizing biomass feedstock, producing sustainable aviation fuel (SAF), and producing synthetic fuels through the production and use of CO2-free hydrogen. These developments are also described in the carbon neutral action plan mentioned above.

While there are various strategies as described above, the key to reducing CO2 emissions in the chemical industry is to focus on the sources of those emissions: raw materials (feedstocks), electricity, and heat (steam), and to make them CO2-free. From the next section, we will organize the strategies and issues mainly from these three aspects.

3.3.1.2 Strategies for feedstock

From Figure. 2.2 3, coal and oil are used as main raw materials in the chemical and petrochemical sector. The amounts are 129 PJ of coal (about 17%) and 341 PJ of oil (about 45%).

The only way to make these raw materials CO2-free is to convert them to biomass-derived raw materials or to recover CO2 and produce raw materials for petroleum products from CO2. In other words, one is to use bionaphtha to produce petroleum products through conventional processes (naphtha cracking), and the other is to produce petroleum products directly from CO2. The latter is a carbon recycling technology that is being actively researched and developed in Japan; for example, projects are underway in Japan to produce olefins and other products from CO2. Whether all petroleum products can be manufactured from CO2 is a major issue for the future, including the balance between supply and demand.

There are also many issues to be considered, such as how long CO2 will be fixed in petroleum products manufactured from CO2, how to evaluate CO2 after disposal, and if DAC is used, whether the mass balance between CO2 recovery by DAC and supply to products can be maintained.

Incidentally, there have been few attempts to use biomass as a feedstock for the chemical industry in Japan. In December 2021, Mitsui Chemicals imported about 3,000 tons of biomass naphtha (bio-naphtha) from Neste in Finland and fed it into an ethylene cracker at its Osaka Plant. The company plans to produce various plastics, chemicals, and other derivatives from the ethylene cracker. The products will be shipped with biomass certification based on ISCC PLUS (International Sustainability & Carbon Certification) certification. These attempts are just the beginning.

It is an extremely important concept to recycle waste, waste cooking oil, and waste plastics. In Japan, about 85% of plastics are recovered, and the recovery rate is increasing year by year. However, the current breakdown is 22% material recycling, 3% chemical recycling, and 60% thermal recycling. Compared to Europe and other countries, incineration is more widespread in Japan, and thermal recycling is the mainstream.

3.3.1.3 Strategies for electricity

There is first of all the need to decarbonize the electricity used for current end-use technologies. In addition, a decarbonized electricity supply would also provide opportunities for electrification of heat (steam), as discussed in the next section. Therefore, this section analyzes the strategies for decarbonizing electricity supply in Japan in general.

Japan's electricity supply is based on a centralized power supply system. On the other hand, many offices have their own power generation systems. This is very reassuring during periodic inspections of factories and in emergency situations such as disasters, but power generation capacity is not very large.

Japan's electricity composition is 31% coal, 6.4% oil, 39% natural gas, 7.8% hydroelectric, and 12% renewable energy (FY2020). It is difficult to know which type of power source supplied the power from the power plant to the factories and other facilities, because the power is connected to the power grid. Japan relies on imports for most of its fuel for power generation, and the composition of that power depends on the location of power plants and factories.

The use of renewable energy sources is essential to decarbonizing electricity. The petrochemical industry consumes 191 PJ of electricity (Figure. 2.2 3), which would require 43 million kW of solar power or 30 million kW of wind power (converted to 14% and 20% of solar and wind power facility utilization, respectively). Currently, solar power is the most widely installed renewable energy source in Japan, with an installed capacity of approximately 65 million kW (in FY2020). In other words, if the power consumed by the petrochemical industry were to be supplied by photovoltaic power generation, it would require an amount of power equivalent to 2/3 of the existing photovoltaic power generation capacity.

To begin with, Japan has limited land with good solar radiation and wind conditions, and Japan does not have a well-developed power transmission and distribution network for renewable energy, and efforts are currently underway to strengthen this network. We must also not forget to take measures to prevent power output fluctuations due to the instability of renewable energies.

CO2-free electricity supply by means other than renewable energy is also being considered. The key point is how we can get rid of fossil fuels, but we need to think about solid, liquid, and gaseous fossil fuels. For solid fuels, the use of recycled materials such as biomass and waste plastics is mainly effective. For liquid fuels, ammonia and MCH (methylcyclohexane), which are in the spotlight as hydrogen carriers, and methanol and ethanol as CCU products can be considered. For gaseous fuels, hydrogen and synthetic methane as CCU fuels can be considered.

For hydrogen and ammonia, the Japanese government aims to replace 1% of its power supply mix with hydrogen and ammonia by 2030, and to introduce 20 million tons of hydrogen and 30 million tons of ammonia by 2050.

Since methanol and ethanol again produce CO2 when burned, it is necessary to consider using the recovered CO2 as a raw material and recovering the CO2 after combustion. Of course, using CO2 recovered from the atmosphere is very effective (DAC), and CO2 can be isolated by CCS.

In order to construct such a new energy system, NEDO is promoting next-generation R&D that challenges carbon neutrality under the title of "moonshot-type R&D projects" and "green innovation fund projects". However, it is likely to take some time before practical application.

3.3.1.4 Strategies for heat and steam

There are three ways to decarbonize heat: (1) effective utilization of unused heat (waste heat), (2) CO2-free heat sources, and (3) use of electrothermal conversion.

Even though waste heat is generated as a by-product in almost all technical processes, it is often lost without being utilized. For example, incineration of waste materials to generate heat for heating and hot water supply is one of Japan's specialties. Thermal storage technologies, heat pumps, absorption and adsorption chillers, and thermoelectric generators play an important role in the utilization of waste heat. Waste heat can be easily utilized, but the balance between waste heat sources and consumers is very important. In particular, it is necessary to investigate the temperature range, heat content, waste heat flow, timing of heat supply and heat demand, type of heat medium, and local conditions.[1] Effective use of unused heat (waste heat) can significantly reduce fossil fuel consumption and CO2 emissions. However, as long as fossil fuels are used as heat sources, it is not possible to reduce CO2 emissions to zero.

CO2-free conversion of heat sources can be achieved by replacing natural gas, light oil, heavy oil, etc. used as heat sources with CCU fuels, as discussed in section 3.3.1.3.

It is also important to capture the CO2 emitted after combustion (steam production), unless the CCU fuel is produced with CO2 by DAC. Alternatively, CO2 can be isolated by CCS.

In Japan, the development of synthetic methane (e-methane) is becoming active, especially in the gas industry. Methane is produced by synthesizing hydrogen from renewable energy sources and CO2 recovered from factories, power plants, and in some cases, the atmosphere, in a methanation reaction. This synthetic methane can be used immediately as an alternative fuel to natural gas as a heat source in areas of Japan where infrastructure is in place. However, if the CO2 recovered from a power plant or factory is derived from fossil fuels, it will not become carbon neutral unless the emitted CO2 is recovered after it is used (burned) as a heat source.

[1] For the detail, please refer to anther publication from GJETC „Topical paper on the potential of waste heat usage in Germany and Japan“ (January 2023)

As for the electrification of heat using electrothermal conversion technology, it is seen only in small-scale applications. If it is to be made large scale, there are still major issues to be solved, such as securing large scale electricity from renewable energy sources.

3.3.1.5 Timelines

With only a limited time until 2050, if we want to ensure the realization of a carbon-neutral society, we need to make the most effective use of existing technologies and infrastructure while simultaneously developing innovative technologies. The carbon recycling technology roadmap announced by METI indicates that research and development will be divided into three phases as shown in Figure 3-3. Various products can be manufactured from CO2, but products that can effectively utilize existing technologies and infrastructure will be manufactured in Phase 1 through technology demonstrations and put to practical use in Phase 2. For example, minerals that do not require hydrogen (e.g., concrete), bio-jet fuel and polycarbonate, which are already commercialized, are products developed in Phase 1. In Phase 3, when consumption of these products is expected to expand significantly, synthetic fuels and chemicals, which take time to develop and spread, will be put to practical use. However, discussions on the scale of market introduction of raw materials, fuels, and electricity produced by carbon recycling, necessary costs (cost-effectiveness), and CO2 reduction effects have not been discussed in detail. This is a major issue, as it is also a factor in corporate management decisions.

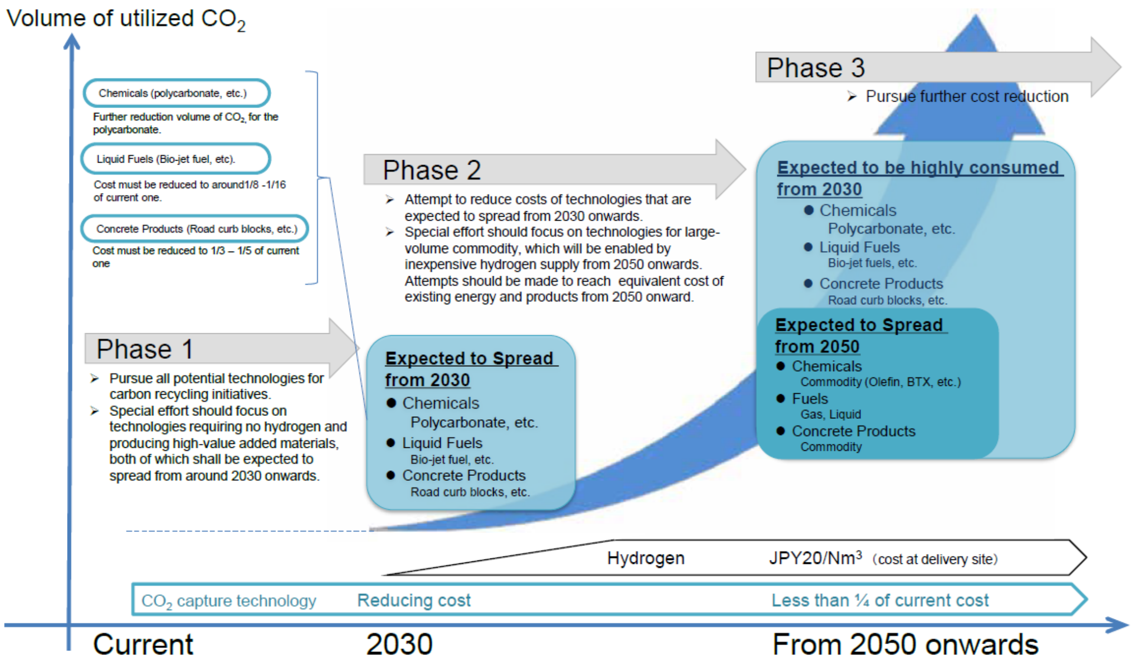


Figure 3-3 Roadmap for carbon recycling technologies

(Source: METI, "Roadmap for carbon recycling technologies", 2019.6)

3.3.1.6 Challenges identified in roadmaps

Technologies for conversion to CO2-free raw materials, electricity, and heat (steam) already exist in reality and it is scientifically possible to produce them toward carbon neutrality. The Carbon Recycling Technology Roadmap qualitatively suggests what and when to introduce these technologies with respect to a time line. If realized, it will bring us much closer to carbon neutrality. However, there is much uncertainty about the CO2 reduction and cost-effectiveness of introducing each technology and CO2-free products. This has caused companies to hesitate to invest. We hope that these R&D efforts will make a significant contribution to promoting the development of innovative technologies and improving cost-effectiveness in order to bridge the gap between the present and the future vision of a carbon-neutral society in 2050.

3.3.1.7 Outlook on discussion beyond the roadmaps

In recent years, major natural disasters have occurred in many countries around the world. Japan is no exception. The global spread of new coronavirus infections caused a major impact on the economy and energy. Above all, Russia's invasion of Ukraine has led to a continuing energy crisis in Japan, Europe, and many other countries, causing energy prices to rise sharply.

Japan has a very low energy self-sufficiency rate, and if supply chains are disrupted due to these effects, the supply of products from petrochemical manufacturers will be disrupted, and the impact on the social economy will be very large. Geopolitical considerations of fossil resources (fuels) have been conducted on various occasions in Japan. Therefore, Japan continues to discuss the correction of overseas dependence on fossil resources (fuels) and the decentralization of production bases. The introduction of carbon recycling technology is essential to realize a carbon-neutral society, and renewable energy is the key to this. In other words, it is quite possible that in the future we will be forced to import renewable energy (i.e., depend on overseas sources), so geopolitical considerations regarding renewable energy will also be necessary in the future.

3.3.2 Conclusions on Japanese pathways

Japan is an island nation with a very low energy self-sufficiency rate. Since energy cannot be exchanged with other countries directly and the domestic pipeline network is not well developed, it is necessary to build an energy system based on energy imports by shipping in addition to developing domestic renewable energy sources to the extent possible. Various strategies published in Japan also describe these ideas as their basic premise.

To reduce CO2 emissions in the chemical industry (petrochemical industry), it is essential to make raw materials (feedstocks), electricity, and heat (steam) CO2-free. In fact, the energy sources used in Japan's chemical industry (petrochemical sector) can be broadly classified into petroleum, coal, natural gas, and electricity. Something must be done about these.

For electricity, it is important to introduce renewable energy sources, but the amount of renewable energy is not infinite. The stability and amount of electricity generated depends on factors such as solar radiation, wind conditions, and the amount of water. According to most studies, Japan cannot meet all its energy needs from renewable energy sources, and in the future it will need to collaborate with foreign countries (importing renewable energy). This idea is connected to the development of carbon recycling technology. The use of substitutes for fossil resources (fuels) manufactured from CO2 (CCU products) will greatly reduce the consumption of fossil resources (fuels) used for raw materials, electricity, and heat (steam). Furthermore, to become carbon neutral, it is necessary to capture the CO2 generated after the CCU product is used, burned, incinerated, or disposed of as waste. Alternatively, CO2 must be captured from the atmosphere and balanced or sequestration by CCS must be considered.

However, there is much uncertainty about the CO_2 reduction and cost-effectiveness of introducing each technology and CO_2-free products. This has caused companies to hesitate to invest. We hope that current and planned R&D efforts will make a significant contribution to promoting the development of innovative technologies and improving cost-effectiveness in order to bridge the gap between the present and the future vision of a carbon-neutral society in 2050.

We are hopeful that energy systems with carbon recycling will play a major role in bridging the gap between the future and the present. We also believe that the introduction of carbon recycling is essential to the realization of a carbon-neutral society, and renewable energy and hydrogen are key. In doing so, geopolitical considerations regarding renewable energy and diversification of its supply will also be necessary in the future, because we will be forced to import renewable energy (dependence on foreign countries) in the future.

4 Comparison of industrial context and decarbonization strategies, and key insights

In the overall comparison, we first compare the initial situation of the two countries and then move on the comparison of the roadmaps and their strategic implications.

Table 4-1 compares the current situation in the chemical industry (petrochemical industry) between Germany and Japan.

Table 4-1 Comparison of the Current State of the Chemical Industry in Germany and Japan

Similarities and common challenges	Differences and specific challenges

Similarities
• Similar size industries
• Mid-century net-zero targets
• Limited domestic resources – import dependent
	Differences
	• Land connections to other countries
	  • Different infrastructures affects value chains, dependencies, and closeness to world market
	• Energy mix to chemical industry
	  • Gas in Germany
	  • Coal and oil in Japan

Common challenges • Finding ways forward to reach net-zero targets • High energy prices	**Specific challenges** • Germany: Increased gas prices

The size of the German and Japanese industries is almost the same. And both countries also share the goal of achieving a carbon neutral society by mid-century. Furthermore, both countries are very similar in that we both lack domestic energy resources and rely on imports from abroad. Both countries have experiences with long term contracts for energy supply to hedge against volatile world market prices, but Germany relied much on Russian oil and gas deliveries and has no established structures with trade agencies under supervision of the government. In common, both Germany and Japan are searching for ways to achieve a carbon-neutral society and have yet to find a solution. Various policy options are discussed such like regulation, carbon pricing including emission trading, and international cooperation. And we are not sure how to deal with the recent increase in energy prices.

The critical difference between Germany and Japan is their geographical environment. While Germany is connected to its neighbours by land and integrated into two physical cross-border production networks, Japan is an island nation surrounded by the sea. This will have a very significant impact on infrastructure, the construction of supply chains among companies, and affinity with the global energy market, which are essential for achieving a stable energy supply. In Germany, the very large cluster comprising the Rhein-Ruhr area and the two North Sea ports of Antwerp and Rotterdam form a unique meta-cluster of its own that covers the complete range of standard polymers and is thus capable to react on the usual market imbalances quite quickly, as platform chemicals can be easily exchanged via pipeline and plant utilisation rates can be stabilized. Particularly in the case of Japan, energy supply by pipeline is currently not feasible, so the country must rely on energy transport by ship, but the topography of the country also hampers the building of pipeline interconnections within the country, so the most of Japanese chemical sites are distributed to several industrial areas without physical interconnections and are more exposed to the world market. In other words, if Japan wants to be prepared for any contingency, Japan needs to find a diversity of energy sources.

The two countries also differ in their energy sources in the chemical industry. Germany mainly uses natural gas when it comes to final energy use and uses oil-products only in the form of by-products, whereas Japan relies on coal and oil as well as natural gas. Thus, Germany's chemical industry has been severely impacted by the high prices of natural gas due to the disruption of natural gas from Russia.

An overview of main similarities and differences in the roadmaps is shown in Table 4-2.

Table 4-2 Comparison of German and Japanese Roadmaps to Achieve a Carbon-Neutral Society

Similarities	Differences
● Mid-century net-zero targets ● Limited domestic renewable resources compared to demand. (import dependence) ➢ Importing synthetic fuels and feedstocks. ● Focus on recycling	● Roadmaps specificity for petrochemical industry ● Physical connections to other countries ➢ Germany: Power grid, pipelines ➢ Japan: No connections. Transport by ship. ● Non-feedstock energy use ➢ Germany: Green electricity ➢ Japan: Range of imported fuels ● Framing ➢ Germany: Renewable resources to improve sustainability and supply security ➢ Japan: Energy security issue and efficiency

Basically, the characteristics of the environment surrounding the chemical industry are directly reflected in the policies and roadmaps. One is the goal of achieving a carbon neutral society by the middle of this century. Another is that both countries are poor in their own energy resources. This means that there is a limit to the supply of renewable energy at competitive prices in the countries themselves, and in the future it will make sense, or they even will have to, rely on imports of renewable energy from abroad as well. Importing renewable energy means not so much electricity, but mainly synthetic fuels and CO2-free raw materials produced by using renewable energy. Both countries have also investigated strategies for carbon cycling in the form of CO2 reuse (CCU) and the chemical recycling of plastic waste.

There are also several differences between the roadmaps of Germany and Japan. First, Germany is connected to its neighbours by land, which allows it to source electricity in a greater geographical electricity system and market, which allows for more compensation of regional fluctuations in the supply of renewable electricity. Hydrogen might also be supplied by pipelines from the North Sea or from countries like Spain or even Morocco. Japan, on the other hand, is an island nation surrounded by the sea, and therefore has to rely solely on shipping of energy. Therefore, as a measure to reduce fossil energy consumption (CO2 emissions) in the chemical industry, Germany is focusing on electrification (but often in hybrid systems to add flexibility to the electricity market), while Japan is assuming that CO2-free energy will mainly be procured in the form of chemical energy carriers overseas and imported by ship.

In Germany, energy security may be achieved by its integration into the European energy markets as well as through diversification of imports of green fuels from overseas, whereas Japan searches to diversify its imports of clean fuels.

Some main differences can thus be explained by their embeddedness into more general overall political strategies. The topic of industrial transition is connected to other strategical objectives and societal developments. This influences the context in which the roadmaps are produced, and thereby the framing of the roadmaps and its measures. For example, the German Energiewende, EU strategies, and targets such as the EU Green Deal puts the German roadmaps in a context focused particularly on complete defossilization and use of renewable resources to improve sustainability and supply security, with energy efficiency as the second pillar. In the Japanese roadmaps, the context of challenges with energy security and the efficient use of energy receives a comparatively greater focus. While the different priorities may shape which strategies are preferred in the different countries, all issues are part of the discussions in both countries, as they all affect their respective industries to different degrees. It is also an opportunity to draw inspiration from the solutions considered in the different context, and thereby find more robust solutions with greater benefits.

5 Conclusions and recommendations

In 2021, the GJETC analyzed potential roadmaps and strategies for decarbonizing the steel industry. The study found that the targets, technologies, and strategies are quite similar in both countries, showing a large potential for cooperation in development of technologies and markets. Compared to the steel sector, this study on the petrochemical industries found that the decarbonization targets are again similar for both countries, but that both the priorities in the technological roadmaps and strategies for decarbonizing feedstocks and energy supply have some major differences, and that even at least within Germany, scenario studies show uncertainties about these priorities. Therefore, cooperation between Germany and Japan may rather need to focus on learning together and from each other, but also on the development of global supply chains for clean CO_2-based hydrocarbons, which play an important role in the strategies of both countries.

Germany can learn a lot from Japan when it comes to diversifying energy supply on the world markets. This learning process has already started – even at the government top level with a visit of the German Chancellor in March 2023 covering this topic. For the future, a liquid world market for green chemical energy carriers and feedstocks, such as naphtha, methanol, hydrogen, or ammonia, is in the interest of both countries. While a room for green ammonia is very likely, the future of hydrocarbon supply to the chemical industry is still open. Many countries still consider fossil oil as a future feedstock, where supply might be extremely monopolized in the future due to a very small remaining market. CO2-based hydrocarbons are discussed in both countries, be it as a fuel or as feedstock. The political incentivization of their use is still not tested at a large scale and both countries may learn here in regard to the different usage of political instruments.

One interesting question is what kind of green hydrocarbon carrier will be a standard commodity of the future. Both countries may learn here from each other when it comes to technical studies, e.g. on methanol-based value chains. Both countries could develop common projects or try to incentivize market creation. During the introduction period, there is a risk of competing interests. However, a first project on a Joint Study Agreement to develop a clean ammonia project in the Port of Corpus Christi in Texas, USA, was launched in February 2023 by the German energy company RWE, the Japanese Mitsubishi Corp. and the Korean company Lotte Chemical[2], showing a potential room for cooperation with a risk sharing between these three energy import dependent and world market integrated industrial countries. This is an example of how Germany and Japan could form coalitions of potential importing and exporting countries, while at the same time developing the technologies needed for both production and transport of the clean fuels.

Cooperation and mutual learning may also help to accelerate the market introduction of other key technologies and to fill gaps and uncertainties in timelines. While the Japanese industry has more technological know-how on industrial heat pumps with high supply temperatures, Japan might learn from experiences in Germany in the flexible use of technologies, such as heat pumps and electrode boilers, in highly volatile electricity markets with a high renewable share. Learnings could be on the technical design level for power-to-heat and their integration into hybrid steam supply systems, on the operation level for chemical companies and grid operators, but also with regard to

[2] https://www.rwe.com/en/press/rwe-supply-and-trading/2023-02-08-rwe-lotte-mc-enter-into-jsa-to-develop-clean-ammonia-project/

the design of policies, e.g., for the electricity markets or subsidy schemes in order to incentivize an electrification that helps to stabilize the electricity system.

With regard to research and development on new technologies to produce petrochemicals both countries can learn from each other. In Germany, biopolymers might have a stronger focus due the existing potentials in the country, while CO2 based technologies seem to have a greater focus in Japan.

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List of Abbreviations, Units and Symbols

Abbreviations

#AGFW	Energieeffizienzverband für Wärme, Kälte und KWK (Energy Efficiency Association for heating, cooling and CHP)
#BMUV	Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz (German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection)
#BMWK	Bundesministerium für Wirtschaft und Klimaschutz (German Federal Ministry for Economic Affairs and Climate Action)
#CHP	Combined Heat & Power
#COP	Coefficient of Performance
#DENA	Deutsche Energie Agentur (German Federal Energy Agency)
#DOE	United States Department of Energy
#EU	European Union
#Fig.	Figure
#FY	Fiscal Year
#GWB	Gesetz gegen Wettbewerbsbeschränkungen (Act against Restraints of Competition)
#KWKK	Kraft-Wärme-Kälte Kopplung (Combined heat, power and cooling)
#LANUV	Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen (State Office for Nature, Environment and Consumer Protection North Rhine-Westphalia)
#LED	Light-emitting diode
#METI	Ministry of Economy, Trade, and Industry (Government of Japan)
#MOE	Ministry of the Environment (Government of Japan)
#NEDO	New Energy and Industrial Technology Development Organization (Japan)
#NRW	North Rhine-Westphalia
#ORC	Organic Rankine Cycle
#PCM	Phase Change Material
#PV	Photovoltaics
#R&D	Research and development
#RED	Renewable Energy Directive
#SMEs	Small and medium-sized companies
#SRC	Steam Rankine Cycle
#Tab.	Table
#TCES	Thermochemical energy storage
#TEG	Thermoelectric Generator
#TherMAT	Thermal Management Materials and Technology Research Association
#WI	Wuppertal Institut für Klima, Umwelt, Energie GmbH (Wuppertal Institute for Climate, Environment and Energy)

Units and Symbols

#%	Per cent
#°C	Degrees Celsius
#CO_2	Carbon dioxide
#g	Gram
#h	Hour
#K	Kelvin
#kW	Kilowatt
#t	Ton

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Executive Summary

When realizing the planned sustainable energy transition, it is crucial to minimize the consumption of finite resources and to move away from the dependence of fossil fuels. In this regard a wide variety of measures - such as energy efficiency, the expansion of renewable energies, or the increasing integration of energy storage systems - are being developed and promoted. Usually, little notice is taken of the **use of waste heat**, which **offers enormous advantages for many different users**. Even though waste heat is generated as a by-product in almost all technical processes, it is often lost without being utilized. This reduces the overall energy efficiency of technical processes, since a significant part of the thermal energy is wasted, leading to unsustainable processes. Thus, **an improved utilization of waste heat can lead to higher energy efficiency and can at the same time reduce energy costs**.

The use of waste heat is rather simple: Processes or machines generate heat through their operation. This heat is then released in the form of heated air or warm wastewater and can be used with the help of a heat exchanger. This technology is also used in heat pumps or ventilation systems for heat recovery. The heat energy can be extracted from the exhaust air or the wastewater via this heat exchanger and is transferred to a separate heat circuit. Such waste heat uses and sources as well as their potential are explained in more detail in Chapter 2 of the present study. **Identifying and utilizing the diverse waste heat potentials** will require a holistic analysis of all production processes as well as the building energy technology for utilization of waste heat from production processes in other processes or in buildings. More generally, waste heat potentials can be identified by examining all waste heat sources and each prospective heat consumer. In this regard, the following criteria must be kept in mind: Temperature level, available heat quantity, continuity of the waste heat stream, timing of heat supply and heat demand, heat transfer medium, and local conditions. Beyond the operational optimization of waste heat utilization in the own company or premise, existing surplus amounts of heat can also be transferred or sold to third parties. Feeding waste heat into local or district heating networks or to neighboring companies can make a **major contribution to** achieving the goal of **a climate-neutral building stock and industry.**

To fully exploit the identified potentials, several technologies can be utilized. The **state of the art as well as future technological trends** are explained in Chapter 3. Important components in waste heat utilization and distribution are among others heat storage technologies, heat pumps, absorption / adsorption chillers and thermal electric generators. Next to several options of those technological standards, Chapter 3 describes **crucial materials and components needed for waste heat utilization** as well as whole **system technologies**.

Furthermore, the present paper provides a condensed overview on the **usage of waste heat in Germany and Japan** (see Chapter 4) as well as its potentials, including technological developments and **policy measures** in both countries. It gives an outlook on the contribution of this energy source to a **sustainable energy supply** for industry, public institutions and communities. Regarding the existing infrastructure, for example for use of waste heat by third parties, Germany mainly holds **district heating grids**, which is only common in the very Northern part in Japan. On the other hand, Japan already has longer experience in the construction and operation of cooling systems, highly efficient heat pumps and Thermoelectric Generators, just to name a few.

In both countries, Germany as well as Japan, various **subsidy programs** to support the use of waste heat have been launched. An exchange of experiences on the effects of the subsidy programs would be desirable here. However, **large-scale "waste heat markets" do not yet exist in both countries**; in contrast to the electricity market, there is no free market for heat, including waste heat. **Political action is needed** on both sides to support the creation of a "waste heat market", potentially as a part of a wider sustainable heat market.

Several **German-Japanese workshops and bilateral exchanges** such as the GJETC have identified a whole range of potential areas of cooperation that can subsequently be further developed in **collaborative projects**, for instance: Optimization of thermoelectric generators, increasing efficiency and demonstrating possible applications for industrial heat pumps such as in the food industry, use of waste heat from data centers, use of waste heat from waste water, concepts for (municipal) heat networks, or methods for developing waste heat registers and local heat planning. Learnings can be derived by looking at **best practice examples from both countries**. Japan for instance possesses a wide knowledge on municipal **waste incineration,** through which heat is generated and supplied for heating and hot water. Those incinerators can be found in municipalities such as Hikarigaoka or Shinagawa. An example for best practices in Germany can be found at the Neckarpark in Stuttgart, where **heat from a sewage system** is used for supplying heating and hot water for a quarter in Stuttgart. More best practice examples from Japan and Germany are listed in Chapter 4.4.

Regarding technologies, a cooperation between German and Japanese research institutes and heat pump manufacturers for the **further development and use of heat pumps** (also in the high-temperature range of 120°C and more) and users would make sense. One technological cooperation that has already started, taking thermoelectric generators into account. This **cooperation between a Japanese company and a German research institute has already been established** as a **follow-up to the German-Japanese workshop** "Industrial Waste Heat Usage - German-Japanese Expert Workshop 2021". This shows, that an **intensified bilateral** exchange regarding technologies and systemic concepts, but also policies, could **enable further synergy effects for industry, research and policy for both countries**.

1 Introduction

In order to realize a sustainable energy transition, energy efficiency is one important part of the puzzle. Energy efficiency makes the transition to renewables sustainable and affordable, and it makes economic sense. Most actions to reduce demand are cost effective and cheaper than investments in new energy supply.

The utilization of waste heat is a possibility of saving energy which had been neglected in the past. In Germany, heat demand for space and process heating is responsible for around one-third of CO_2 emissions in Germany (AGFW, 2020). To achieve the German government's climate protection targets and make the heating sector climate-neutral by 2045, the considerable waste heat potential in industry, commerce, services and trade must be harnessed. Even though waste heat is generated as a by-product in almost all technical processes, it is often lost without being utilized. This reduces the overall energy efficiency of technical processes. Thus, an improved utilization of waste heat can lead to higher energy efficiency and can at the same time reduce energy costs.

The usable potential is enormous. In Germany, for example, around 50 % of process heat in industry alone is still emitted as waste heat instead of being used for a secondary heating purpose (Deller, 2022). However, there is largely untapped potential not only in industry but also in other areas, such as waste heat from data centers or municipal sewage systems. Low-temperature sources, such as cooling circuits and exhaust air, are also increasingly becoming the focus of potential identification and development. Processes that currently generate waste heat are being converted with a view to increasing efficiency, changing energy sources from fossil fuels to renewables, and using waste heat within the company or between factories, either directly or, for example, by using heat pumps.

In order to find sustainable solutions, it is crucial to find out which waste heat sources are potentially useful and available in the long term. Therefore, when identifying and quantifying potential, the future perspective must always be considered.

The present paper provides a condensed overview on the potential and usage of waste heat in Germany and Japan, on technology developments, and on policy measures in both countries. Further, it gives an outlook on the contribution of this energy source to a sustainable energy supply for industry, public institutions and communities.

In Chapter 2, general overviews of potential waste heat uses, available heat sources/heat sinks and their temperature level, and methods for identification of potentials and examples are given.

Chapter 3 informs on the technology for using waste heat: state of the art and future trends for the main technologies and components for the use of waste heat, such as heat storage systems, heat pumps, chillers, electricity generators, and system technologies.

Afterwards an overview on waste heat usage in practice is given separately for Japan and Germany in Chapter 4. This includes the current state of usage and the potential for expanding it, policy measures to overcome barriers for waste heat utilisation, and finally best practice examples.

Finally in the conclusion (chapter 5), suggestions for priority research fields for German-Japanese cooperation are provided.

2 Waste heat sources and uses

Identifying and utilizing the diverse waste heat potentials usually requires a holistic analysis of all production processes as well as the energy technology for utilization of waste heat from production processes.

Beyond the operational optimization of waste heat utilization in the own company or premise, existing surplus amounts of heat can also be transferred or sold to third parties. Due to high transaction costs in project preparation and the coordination of involved actors, only a few projects of this type have been implemented in the past. However, feeding waste heat into local or district heating networks or to neighboring companies can make a major contribution to achieving the goal of a climate-neutral building stock and industry.

Basically, a distinction is made between internal and external waste heat utilization. Internal utilization is in the own company or premise, while external waste heat utilization refers to third parties.

Internal waste heat prevention and utilization:

a) Reduction of the occurrence of waste heat through e.g. thermal insulation, or process optimization.

b) Reintegration of waste heat into the same process (heat recovery, e.g., through combustion air preheating or preheating and/or drying of the starting materials)

c) Use of the waste heat outside of the process of its origin at the highest possible temperature level (integration into other processes or space heating/hot water or steam preparation)

d) Transformation into other useful energy forms (electrical energy, air conditioning/cooling)

External waste heat utilization:

Transfer of waste heat that cannot be used internally to third parties (e.g., to neighboring companies or for heating adjacent residential or business premises)

2.1 Heat sources/heat sinks and their temperature level

The following figure shows typical **sources of waste heat** in the manufacturing sector and typical temperature levels for these.

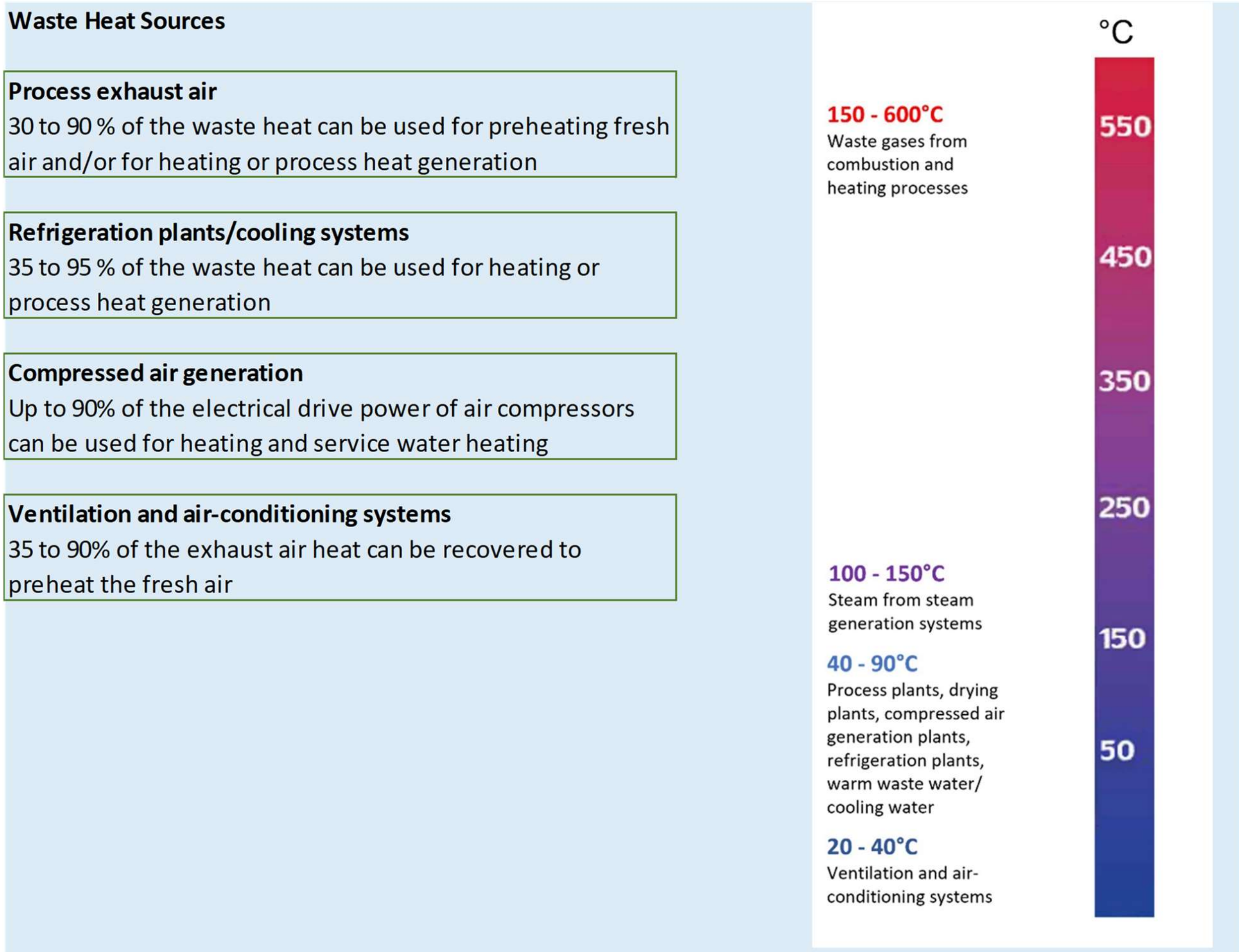


Fig. 1 Typification of waste heat sources (DENA, 2015)

A **heat sink** is the part of a system where it transfers energy to an adjacent system. In other words, heat is lost from the system at the heat sink, which is why heat sinks used to be generally referred to as "heat losses". It is initially irrelevant whether the release of heat is desired or undesired.

Desirable heat sinks are found in both heating and cooling systems. In the heating system, for example, the radiator is referred to as a heat sink because it is here that the heating system releases heat energy into the room air. However, the heat exchanger through which a heat pump is supplied with heat is also a heat sink, because the respective heat source (heat transfer medium/working medium) releases heat (to the downstream heat network) there.

In addition, the term heat sink is occasionally used with reference to a larger system that uses the heat, such as a heating network. In this context, the individual consumers of the heat provided can also be referred to as heat sinks.

The temperature level of heat sinks can be very different and can often be influenced. For example, in the heating sector, flow temperatures of around 35 °C are sufficient for low-temperature heating systems such as underfloor or wall heating, while systems with radiators typically require flow temperatures of between 50 °C and 60 °C at maximum heat demand on cold days. In conventional heating networks, the flow temperature is approximately between 60 and 90°C. In the industrial sector, much higher temperatures are also required.

2.2 Methods for identification of potentials and examples

The use of a waste heat register brings together suppliers and users of waste heat; if necessary, it can also be implemented in connection with a so-called "waste heat information exchange". Companies can report their waste heat potential there and potential users such as housing associations, energy suppliers or other commercial enterprises can research waste heat sources and sinks and obtain information on waste heat utilization.

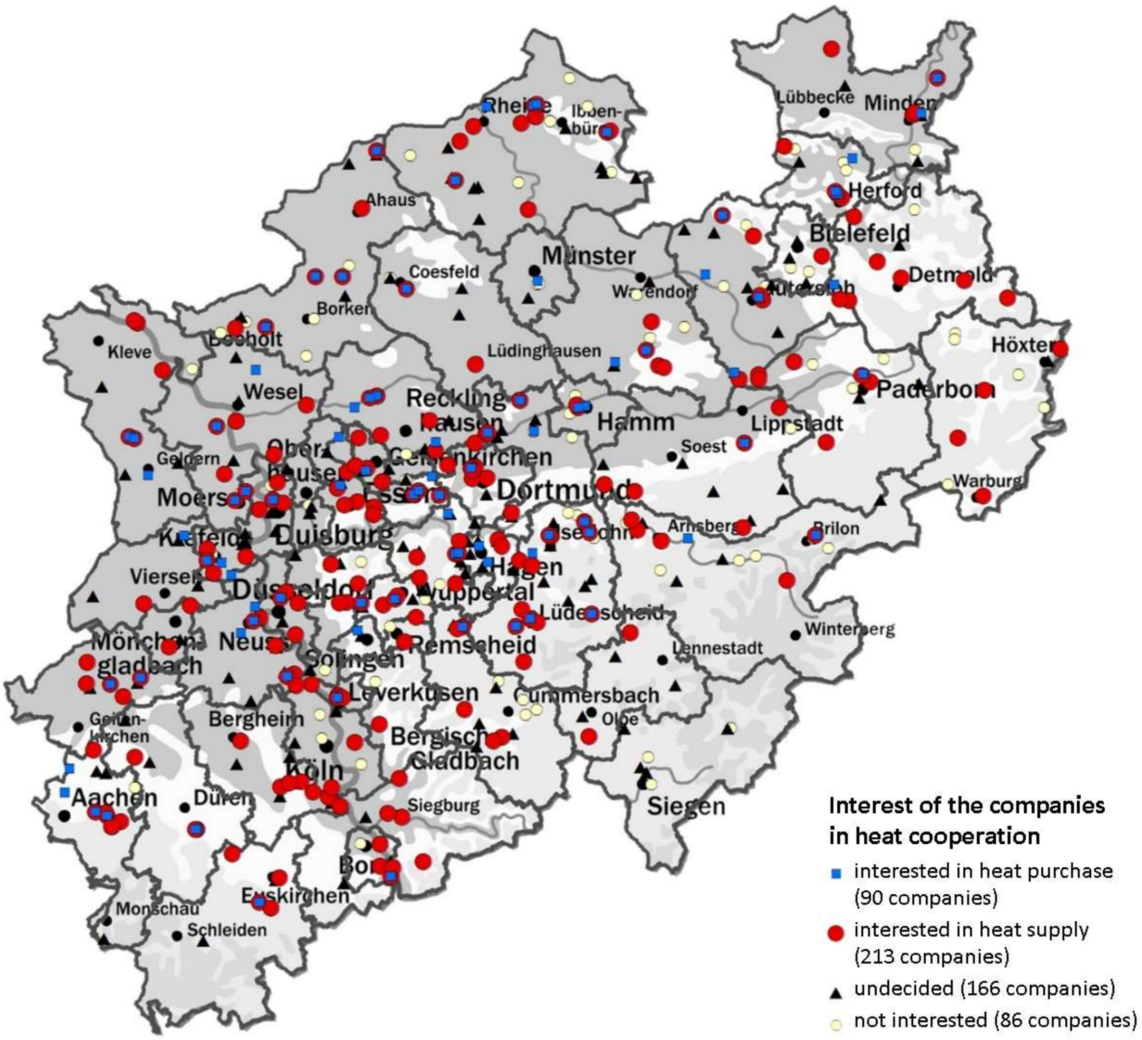


Fig. 2 Result of surveys of more than 1,850 companies (with a response rate of almost 30 percent) in the federal state of North Rhine-Westphalia on waste heat potential and interest in waste heat cooperation or external waste heat utilization. (Landesamt für Natur, Umwelt und Verbraucherschutz (LANUV) Nordrhein-Westfalen, 2019)

Methodology for the preparation of waste heat cadastres:

The **top-down** method uses available nationwide statistical data on energy consumption in industry to determine a theoretical amount of waste heat, which is then broken down to the county or municipality level. This breakdown can be based on employee or sales figures, for example. The sole use of statistical data eliminates the need to survey participating companies, thus enabling rapid processing.

The statistical basis for the waste heat potential in Germany can be the study "Abwärmenutzung - Potentiale, Hemmnisse und Umsetzungsvorschläge" (Waste Heat Utilization - Potentials, Barriers and Implementation Proposals), which was prepared by IZES gGmbH (Grote et al., 2015) on behalf of the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety in 2015. In addition to an overview of the technologies, this study also provides the status of current publications in Germany and at the international level. In addition, an estimate of the potential can be made based on data from the Federal Statistical Office (energy consumption per industry and industry data).

This is opposed by the **bottom-up** method. For this variant, a significantly higher effort is required. Here, the specific data for each company must be recorded and processed by means of surveys, such as in the example in figure 2-2. The appointments required for this survey with subsequent visits to the companies mean that long-term planning is necessary. In addition, experts must be consulted for the data collection and, above all, the subsequent evaluation. Each company has different processes and, consequently, boundary conditions that need to be considered in a differentiated manner and can only be correctly assessed and evaluated with background knowledge.

Against the background of increasing energy efficiency, the data obtained can also be used to investigate whether and how individual companies in selected industrial and commercial areas can join forces. In addition to the focus on industrial waste heat utilization, this will also provide a basis for establishing a joint infrastructure (local heating networks) for the industrial and municipal sectors.

2.3 Criteria for assessing waste heat potentials

To identify waste heat potentials, an examination of each waste heat source and each potential heat consumer should be carried out regarding following criteria:

- Temperature level: the higher, the easier it is to utilize the waste heat.
- Available heat quantity: It will support cost-effectiveness, if the available quantity is in the same order of magnitude as the demand on the utilization side.
- Continuity of the waste heat stream: This has a positive effect on the economic efficiency of waste heat utilization.
- Timing of heat supply and heat demand: Simultaneous occurrence simplifies waste heat utilization.
- Heat transfer medium: Medium-bound waste heat, such as exhaust air streams or cooling liquids, can be used much more easily than diffuse waste heat, which must first be collected and removed for further use.
- Local conditions: If possible, avoid transport losses and check the space availability for the installation of storage technologies, for example.

3 Technology: state of the art and future trends

The use of waste heat is rather simple: Processes or machines generate heat through their operation. This heat is then released in the form of heated air or warm wastewater and can be used with the help of a heat exchanger. This technology is also used in heat pumps or ventilation systems for heat recovery. The heat energy can be extracted from the exhaust air or the wastewater via this heat exchanger and is transferred to a separate heat circuit.

Depending on the temperature range in which the waste heat occurs and the intended use, the following technologies (which are described in the following chapters) may be considered for waste heat utilization:

Temperature range	**Intended use**			
	Electricity generation	**Production at different temperatures**	**Space or water heating**	**Cooling**
High (> 350°C)	Steam turbine, Stirling engines, thermoelectric systems; heat storage systems	Extraction of higher temperature waste heat from power generation; heat storage systems		
Medium (80 to 350°C)	Organic Rankine Cycle (ORC), thermoelectric systems; heat storage systems	Extraction of medium temperature waste heat from power generation; heat storage systems	Local and district heating; Extraction of lower temperature waste heat from power generation; heat storage systems	Absorption chiller
Low (< 80°C)		Heat pumps; preheating; heat storage systems	Heat pumps; space heating, domestic water heating; return temperature boosting; heat storage systems	Adsorption refrigeration

Tab. 1 Waste heat – appropriate technologies depending on intended use and temperature range (based on C.A.R.M.E.N. eV, 2020)

3.1 Heat storage

Waste heat streams may vary with time, as may the demand for their utilization, and they may not directly match in time. Therefore, heat storage is an important component in waste heat utilization and distribution. While for the use of waste heat in internal processes, the necessary storage time is usually only hours or days, it is particularly interesting for heating buildings to use large storage tanks, which can provide the energy required for several days, weeks, or even months. Heat accumulators can be classified according to the time period over which the generated thermal energy is to be stored. These include, for example, buffer, short-term or long-term storage. On the other hand, heat accumulators are divided into sensible, latent or thermodynamic storage units according to their basic operating principle.

Buffer storage

In the form of large water tanks with varying capacities, they store heat on an hourly or daily basis. Especially in the industrial sector, buffer tanks are used to better match fluctuating waste heat supply and heat demand on the user side, e.g. in combination with heat recovery systems and/or heat pumps.

Short-term storage

With a storage period of up to two days, this type of heat storage is mainly used with wood boilers, solar or domestic hot water storage systems to balance heat supply and demand. It is also useful in industrial applications to use waste heat in cyclic processes and applications, and thereby to recover waste heat that would otherwise be lost.

Long-term storage

Long-term storage, also called seasonal storage, can store heat for weeks or months and is suitable, for example, to bridge the transition from the warm to the cold season. In addition to using heat from renewable energy sources, they are thus also well suited for storing waste heat. The imbalance between heat supply and demand is thus minimized.

Sensible heat storage

These storage systems use the so-called sensible or tangible heat of liquid or solid storage media such as water, magnesite, concrete, or earth. Energy is absorbed and released by changing the temperature of the storage medium. While heat is supplied to a storage medium during the layering process, which then increases its temperature, the medium releases the stored thermal energy again during discharge, which can then be used for heating, among other things. Examples of applications are hot water or steam storage as well as gravel water or geothermal probe heat storage.

Latent heat storage

This type of storage makes use of the change in aggregate state, from solid to liquid or vice versa. The storage units are filled with PCM (Phase Change Material). When a storage medium changes its aggregate state from solid to liquid, it absorbs heat. The latent heat remains bound in the material and can be released and made usable again at a later time by physical action. Latent heat storage entails a higher cost than sensible heat storage, but the corresponding benefits are a much higher storage capacity per volume and a stable temperature of the heat released. Salt hydrates or kerosenes are suitable for heat storage, while water or aqueous salt solutions are suitable for cold storage. An example of latent heat storage is ice storage, which uses crystallization energy - the energy released when water freezes. Latent heat storage systems are also attractive when mobile systems are to be used for heat transport because of too great distances to the user of the waste heat or too low heat flows, so that installation of a pipe connection is not cost-effective.

Thermodynamic storage

Thermodynamic reservoirs are reversible systems, which can be divided into sorption reservoirs and reservoirs with reversible chemical bonds. While the latter are still largely in the research and development stage, the former are mostly used in the form of adsorption storage systems with water as the working medium. Such a storage system works as follows: Air at a high temperature is supplied to the solid storage medium. This causes the water contained in the storage medium to vaporize, and the resulting steam is extracted. This vapor is liquefied again in a condenser, and the water remains there. During discharge (adsorption), the water evaporates again due to the supply of heat. This vapor accumulates on the sorption material (usually substances with large internal surface area and hygroscopic properties such as zeolites or silica gels), releasing energy and heating the air.

Thermochemical heat accumulators

At present, various research projects are being carried out on thermochemical heat accumulators (TCES). One example is a process in which boric acid is converted into boric oxide and water by adding heat. During the back reaction, the heat is released again. According to the Vienna University of Technology, this process, which has a high energy density, is ideally suited to the use of waste heat from industrial plants, which can be stored in an environmentally friendly manner for a virtually unlimited period of time (SAENA GmbH , 2016).

3.2 Heat pumps

3.2.1 General information

If the temperature level of the waste heat is not sufficient for direct use, heat pumps can be used. In this case, the waste heat is raised from a low to a higher temperature level with the aid of supplied drive energy and thus made usable for other purposes.

In a heat pump, heat is extracted from the waste heat source. In Germany, the achievable temperatures of compression and absorption heat pumps are specified as 65 °C, and up to 90 °C for special solutions of compression heat pumps.

The differences between heat pumps are primarily in the place of heat generation and the medium of heat transfer. In addition to the four "standard" heat pumps named below, a further distinction is made on the basis of the heat pump's drive. Each heat pump uses a coolant that is evaporated and recompressed in the cycle to generate heating energy (exception: air-to-air heat pump).

- Air-to-air heat pump: for example, waste heat from the ventilation system is used to heat the building.
- Air-to-water heat pump: for example, heat is extracted from the ambient air to heat a building via a water-based heating system.

- Brine-water heat pump: Heat from the ground is used to heat the building via a water-based heating system.
- Water-to-water heat pump: Heat is extracted from a water reservoir to heat a building or process.

Except for the brine-water system, the other three processes can also be used for waste heat utilization. The air or water source feeding the heat pump could carry the waste heat stream, and the higher temperature heat emerging from the heat pump could be used either in a production process or to heat buildings.

In sorption heat pumps, the drive energy is supplied in the form of heat (principle of thermal compression) - instead of electricity as in compression heat pumps.

Currently in R&D projects, a temperature range of up to 160 °C was achieved through the development of suitable refrigerants. For absorption heat pumps, on the other hand, a temperature of up to 300 °C is considered feasible. Absorption and adsorption heat pumps are mainly used for waste heat recovery in the industrial sector (DENA Broschüre Abwärmenutzung, 2015; DryFiciency, 2021).

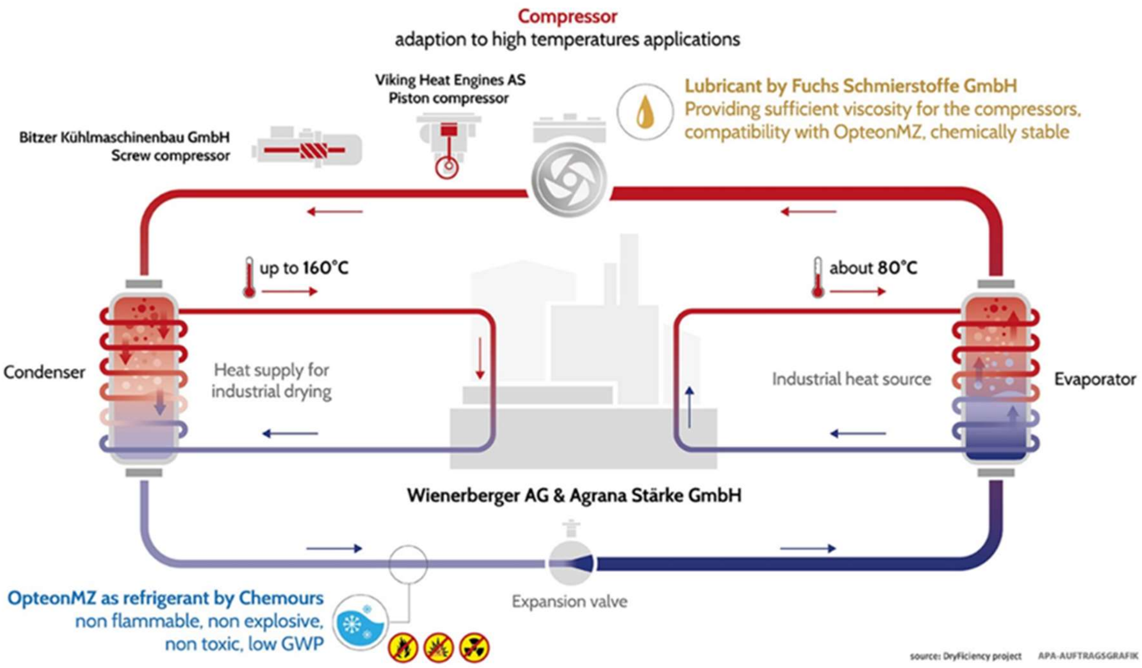


Fig. 3 Example of a high temperature heat pump. (Source: DryFiciency Project, 2021)

A heat pump heating system consists of three parts: the heat source system, which extracts the required energy from the environment; the actual heat pump, which harnesses the extracted environmental heat; and the heat distribution and storage system, which distributes or temporarily stores the thermal energy in the house or, as process heat, for industrial applications.

As a measure of the efficiency of a heat pump, the so-called COP value, or "coefficient of performance", indicates the ratio of the heat generated by the heat pump to the drive energy (electricity) required for this. Thus, the COP depends on several parameters in the heating system – the efficiency of the heat pump itself, the flow temperature of the heating system and the temperature of the environmental energy.

3.2.2 Industrial and domestic heat pumps

Today, more than 1 million heat pumps are already in use in Germany (even though only few of them are used for waste heat utilization), and the trend is rising thanks to extensive subsidies (Bundesverband Wärmepumpe, 2022). The classic application in Germany / Central Europe lies in the field of heating technology, but the use of heat pumps in industry is also showing an upward trend.

3.2.3 High temperature heat pumps

A high-temperature heat pump raises the temperatures of the environmental heat sources to a particularly high level. While conventional systems barely get above a flow temperature of 65°C, high-temperature systems achieve values of 80 to 100°C or even above.

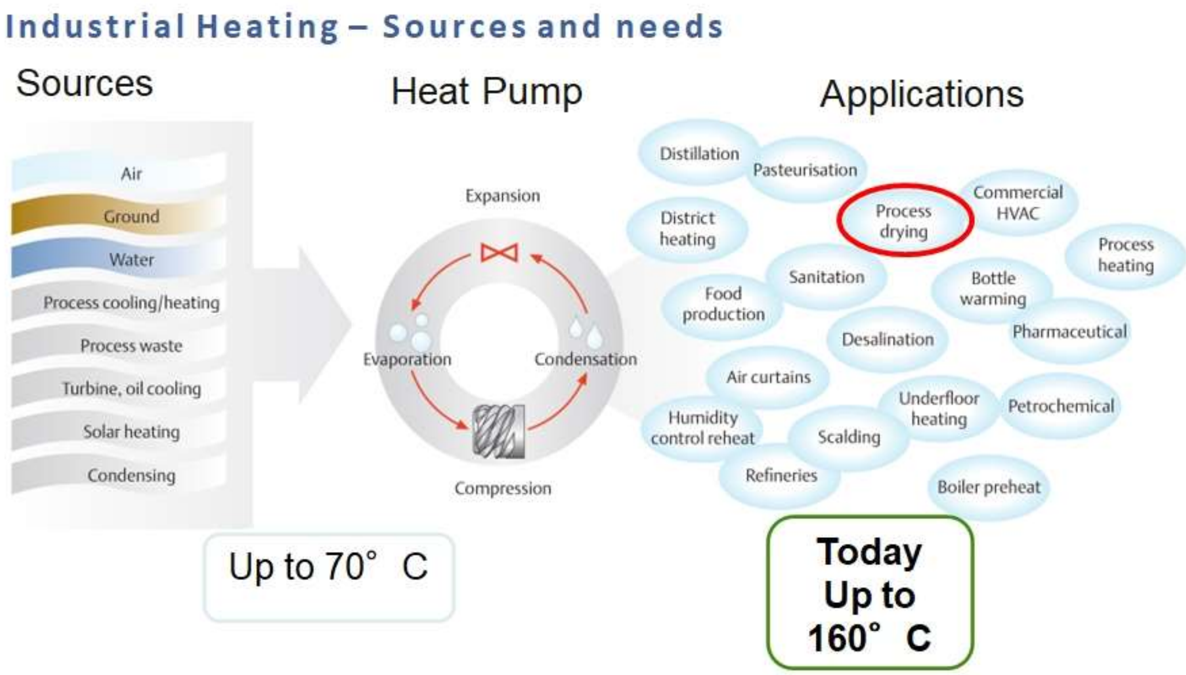


Fig. 4 Industrial heat pumps, heat sources and applications (Source: European Heat Pump Association EHPA, 2021)

While heat pumps provide temperatures of up to approx. 70°C in most cases to cover heating requirements, this temperature range is now being extended to up to 160°C. This results in a wide range of possible applications for the heat pump.

3.2.4 Different system variants for the utilization of heat pumps

Cascading

Cascading (interconnection) of heat pumps is nowadays often used for larger heat pump systems in order to match the output to the respective heating demand. This is because while today's heat pumps in the smaller output range have appropriate compressor technology (inverter compressors or modulating heat pumps) to adjust the heating output according to demand, the heat pump output can no longer be adjusted via the compressor alone in the case of larger fluctuations in demand. Cascade connection and extensive capacity modulation increase the annual performance factor and thus improve the economic efficiency of a cascade system compared to hybrid heat pumps.

The use of heat pump cascades is especially possible and sensible where

- large heating capacities are required,
- the heating, hot water and cooling requirements fluctuate greatly or have to be covered in parallel,
- even large heat pumps reach their performance limits.

Combining heat pumps with renewable energy systems

Another popular form of heat pump operation is the combination of renewable energy systems such as PV plants and heat pumps. This is especially used for providing heat for buildings.

Operating costs of heat pumps as well as CO_2 emissions can be significantly reduced by using the self-produced solar power. The use of solar electricity is all the more economical because it is now increasingly sensible to use the electrical energy produced by photovoltaics oneself instead of feeding it into the grid. At the same time, more self-use increases the economic efficiency of the photovoltaic system.

3.3 Absorption and Adsorption Chillers

An absorption chiller is a refrigeration system that uses thermal compression to raise thermal energy to a higher temperature level. It can be used for cooling or heating (heat pump) buildings as well as processes and is considered particularly energy-efficient. One reason for this is the fact that the electricity requirement is more than 90 percent lower than that of conventional systems. The energy required to increase the pressure and temperature of refrigerants can also be provided in part from renewable sources or from waste heat.

While the refrigerant is absorbed by a liquid solution during absorption, it attaches to a solid during adsorption. An example of this is the zeolite heat pump, an adsorption refrigeration machine in which vaporous refrigerant accumulates on the surface of a porous rock. The pressure and temperature increase here also takes place with heat that comes, for example, from a waste heat stream or a biomass heating system.

Like absorption chillers, also adsorption chillers are thermally driven refrigeration systems. They consist of two working chambers filled with sorbent as well as a condenser and an evaporator. Silica gel is used as the sorbent and water as the refrigerant.

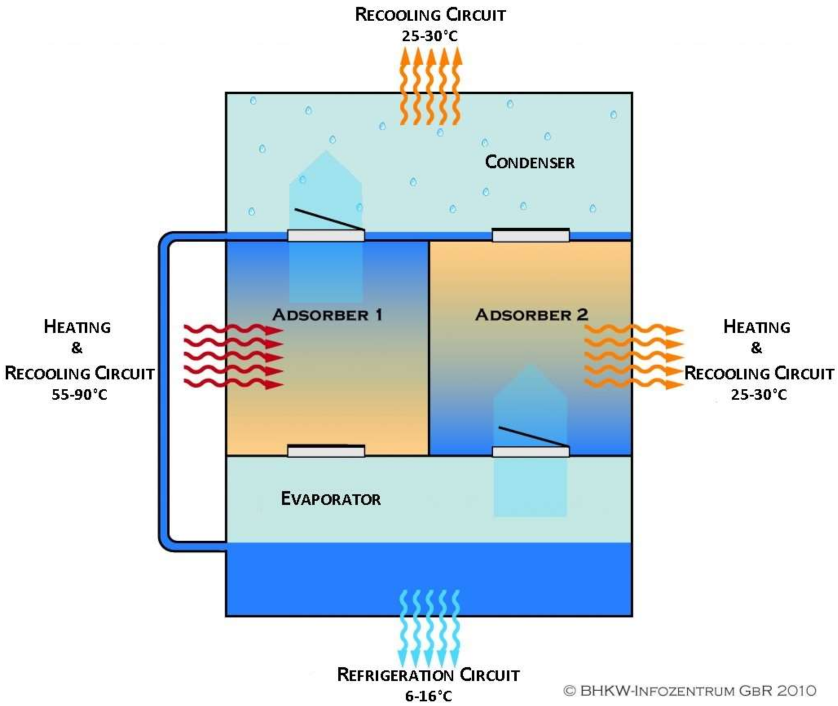


Fig. 5 Principle diagram adsorption chiller system. Source: "KWKK Informationsseite zu Kraft-Wärme-Kälte-Kopplung", (BHKW Infozentrum, 2022)

Two processes take place simultaneously. One is the evaporation of the refrigerant and adsorption of the resulting refrigerant vapor by the adsorbent. On the other hand, the desorption of the refrigerant bound in the adsorbent and subsequently the condensation of the resulting vapor. Since it is necessary to switch cyclically between two adsorber beds, only a quasi-continuous process can be realized with adsorption chillers. Water-silica gel adsorption chillers are particularly suitable for district heating and solar thermal applications, since they can still utilize drive temperatures of 60° C. The low COP (approx. 0.4), the high investment costs and the large weight and construction volume make it difficult to use adsorption chillers and usually make them uneconomical. In addition, the maximum permissible cooling of the heating water is a ΔT of 13 K, but only 5 - 6 K at low temperatures.

3.4 Thermal electric generators (TEGs)

Thermoelectric generators can convert waste heat into electricity. A TEG consists of heat exchangers for hot and cold media and thermoelectric modules in between. Despite the still comparatively low efficiency of TEMs, TEGs offer advantages over other power generation technologies. The passive components have no moving parts, are virtually maintenance-free and can be integrated into existing systems thanks to their compactness.

Currently, compared to other techniques (like ORC and SRC) the payback period of TE (Thermoelectric) technology is still one of the highest. Depending on the waste heat source, individual TEG waste heat recovery systems must be designed and thus the costs are increased. So in the future the production costs of TEG have to be significantly reduced by a couple of measures e.g.:

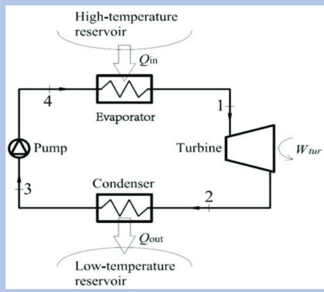
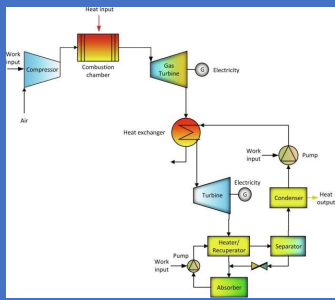
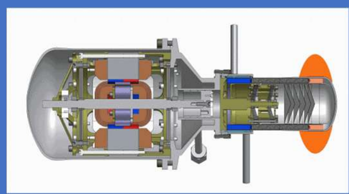
- Advanced TE materials
- New concepts for mass production of TE materials as well as lower-cost TEG manufacturing
- Automated fabrication techniques for mass production of complete TE systems

Under these conditions, TE systems currently may have better chances for producing electric power from smaller waste heat sources (lower temperatures or waste heat flows), which are not usable for ORC and SRC and for smaller applications like power supply of sensors at movable plants/processes.

In addition to power generation from waste heat, TEMs can also be used where cooling is required with little temperature difference or no requirements for economy.

3.5 Other technologies for producing electricity from waste heat: ORC-, Kalina- and Stirling-process

Thermal power engines: Other technologies available for generating electricity from waste heat are for example, the steam turbine, the Kalina process, the ORC process, and the Stirling engine. All these processes operate with an external heat source and therefore are suitable for the use of waste heat. Which technology can be used most advantageously is mainly determined by the temperature level of the waste heat.

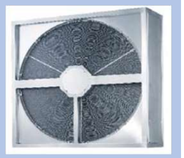
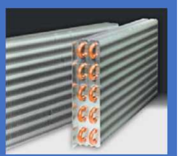
Technology	Working media	Efficiency	Application temperature	
Organic Rankine Circle (ORC)	for each upper temperature level there is another optimal working medium: e.g. R600a (isobutene), R143a (trifluoro-1,1,1-ethane) (Fischer et al., 2007)	approx. 17-20% (Fischer et al., 2017)	approx 80-350°C (Grube et al., 2017)	 (Wang et al., 2017)
Kalina process	principally a modified Rankine cycle, which utilizes the mixture of two different working fluids (water and ammonia).	can improve power plant efficiency by 10% to 50% over the Rankine Cycle depending on the application (Kalina Power, 2015)	approx. 60-200°C (Elsayed et al., 2013)	 (Dinçer & Bicer 2019)
Steam turbine	Water (Steam)	Up to approx. 45%, depending on steam temperature and pressure (Paschotta, 2021)	up to approx. 600 °C	 (Energate Messenger, 2013)
Stirling process	Among others: Helium, Hydrogen, Nitrogen Air	Approx. 10 to 35%, depending on type, temperature and pressure of working medium (gas) (Infinia Corp, 2006)	up to approx. 800°C	 (Infinia Corp, 2006)

Tab. 2 Examples of thermal power processes available for generating electricity from waste heat

3.6 Heat exchangers

Heat exchangers have the task of transferring heat from a warm medium to a colder one. In the process, both media are directed past a heat transfer surface to and from which the heat is transferred.

There are many forms of heat exchangers for the utilization of waste heat:

Technology	application	Power class (thermal)	application temperature	
Rotary heat exchanger	air (gas) / air (gas)	up to 1,600 kW	up to 300 °C (650 °C in the high temperature range)	
Heat pipe heat exchanger	air (gas) / air (gas)	3 W - 3 kW (per heat pipe)	up to 700 °C	
cowper (recuperator)	air (gas) / air (gas)	< 140 MW	up to 1,300 °C	
Finned tube heat exchanger	air (gas) / fluid	5-1,000 kW	up to 400 °C	
Spiral heat exchanger	fluid/fluid; air (gas) / fluid	20-800 kW	100-450 °C	
Plate-fin heat exchanger	air (gas) / fluid	1-900 kW	up to 900 °C	
Plate heat exchanger	fluid/fluid	2-400,000 kW	up to 150 °C (900°C for welded plate heat exchangers)	
Shell and tube bundle heat exchanger	fluid/fluid	2-20,000 kW	up to 300 °C	
Double-tube heat exchanger (shell and tube heat exchanger)	fluid/fluid	1-3,500 kW	up to 200 °C	

Tab. 3 Overview: types of heat exchangers. (Source: brochure "Technologien der Abwärmenutzung" Sächsische Energieagentur - SAENA GmbH, 2016)

3.7 Materials and components

Heat storage system with Phase Change Materials (PCM):

Latent heat storage systems function by exploiting the enthalpy of thermodynamic changes in the state of a storage medium. The most commonly used principle is the utilization of the solid-liquid phase transition and vice versa (solidification-melting) (phase-change materials - PCM). When charging the contents of commercial latent heat storage systems, special salts or kerosenes are usually melted as the storage medium, absorbing a great deal of energy (heat of fusion) in the process, such as dipotassium hydrogen phosphate hexahydrate. Discharge takes place during solidification, with the storage medium releasing the previously absorbed large amount of heat back into the environment as solidification heat.

There are now many PCMs on the market in Germany in the temperature range -30 to 100°C. At temperatures up to 0 °C, water and aqueous salt solutions are used; in the range 5 to about 150°C, kerosenes, fatty acids, salt hydrates and their mixtures are mainly used, and for some years now sugar alcohols. Above about 150 °C, salts and their mixtures can be used (Sonne Wind & Wärme, 2008).

Materials for heat exchangers:

Corrosive components in the waste heat stream influence the lifetime and material selection for heat exchangers. To avoid the failure of aggressive condensate in gas heat exchangers, plants are designed so that the outlet temperatures are above the dew points of the corrosive components of the waste heat stream. As a result, the minimum exhaust gas temperatures vary with the composition of the fuels or due to process-related components in the exhaust gas. For example, the minimum exhaust gas temperature for the use of natural gas is given as 120°C, while temperatures of 150 to 175°C are given for the use of sulfur-containing oils and coal. As a result of process-related sulfur contents in the exhaust gas stream of glass melting furnaces, the minimum exhaust gas temperatures there reach 270 °C (cf. U.S. DOE, 2008). In addition, depending on the composition of a heat stream, deposits and biofilms can form that can degrade heat transfer in heat exchangers, reduce flow, and cause heat exchanger failure. (Hirzel et al., 2013)

3.8 System technologies

3.8.1 Heating networks

Feed-in of waste heat into existing heating networks:

Priority is given to avoidance and internal use. Feeding waste heat into a heating network can be an interesting option, but some conditions must be considered:

- A large part of the waste heat does not occur continuously.
- Waste heat can often only be used as an additional heat source. If the industrial process is changed over, the waste heat may no longer be available.
- A suitable contractual arrangement must be made between the industrial plant and the external heat user.
- The industrial plant and the heat user enter a long-term commitment to each other.

- The extraction and feed-in of heat is usually associated with high investments.
- The sale of heat may not be considered the core business of the heat supplier.
- Larger heat storage capacities may be required to couple supply and demand because of the difference of timing.

Low-temperature district heat network technology

The heat networks currently used for local or district heating generally require flow temperatures of 70 to more than 100°C. When waste heat is fed into these networks, the existing temperature level of the waste heat must of course be adapted to the flow temperature of the heat networks. This is made possible, for example, with the aid of heat pumps.

However, a heat supply can already succeed with low temperatures between 5 and 35 degrees Celsius; especially in densely built-up new construction areas or, for example, in energy-refurbished urban quarters. These buildings have a low heating requirement and need low flow temperatures. Suitable for cold local heating. The cold heat networks are - physically correct - called anergy networks. A mixture of water and glycol (brine) usually flows through the pipe system to protect against frost damage.

Due to the low temperatures in the network, the difference to the temperature in the ground is also only slight. This means that there are only minor losses in the pipe network and there is no need for often cost-intensive insulation of the network's piping, because ideally the network absorbs the ambient heat directly. However, due to the small temperature difference between the supply and return temperatures and the overall low temperature level, large flow rates, larger pipelines and a higher power requirement for the pumps are needed. In principle, reverse operation is also possible with these networks in order to realize the cooling of buildings. This will become more and more important as temperatures rise in the future.

In order to be supplied via these low temperature networks, the houses must have a decentralized heat pump, as the operating temperatures are not sufficient for the production of hot water and heating. In addition, the waste heat generated in this process can be fed back into the heating network. In this way, the users are not only customers, but can also act as prosumers. Depending on the circumstances, they can consume or produce heat or cold (Verbraucherzentrale Schleswig-Holstein, 2021).

3.8.2 Systems for heat recovery and storage for the industry

Waste heat, especially from industrial processes, offers great untapped potential for energy efficiency and is therefore increasingly becoming the focus of efficiency planning. For example, heat recovery from heated building air can save 20-30 percent in space heating costs, and waste heat recovery from industrial processes can even generate more heat than is needed for space heating.

3.8.3 Waste heat in trade and commerce:

Just as in service- or office buildings, it can be worthwhile to use the waste heat from a workshop or production hall: In summer, the heat that is lost can be used to heat water, and in winter it can additionally support the heating system. Depending on the building and the company, an investment in heat recovery can pay for itself within a few years.

The cost-effectiveness of waste heat recovery in industrial or commercial operations primarily depends on the following factors:

- Room size
- Processes in the company
- Heating system

4 Overview on Waste Heat Usage in Germany and Japan

This Chapter gives an overview on waste heat usage in practice, separately for Japan and Germany. This includes the current state of usage and the potential for expanding it, policy measures to overcome barriers for waste heat utilization, and finally best practice examples.

4.1 Current state of Waste Heat Usage

This chapter mainly covers information on external use of waste heat, as in most cases only data for external use of waste heat are available, since most of the Japanese and German companies do not publish data about their internal heat fluxes. Although internal use of waste is already common in many factories in Japan and Germany, it was not possible to obtain meaningful data for Japan and Germany.

4.1.1 Japan

Power plants

The power industry discharges a large amount of waste heat with relatively low-temperature. The latest gas turbine combined cycle power plants are able to utilize about 60% of the heat in the entire power plant through the reuse of waste heat from gas turbine and the use of high-efficiency equipment. However, the amount of the remaining 40% of waste heat, which is relatively low temperature, is enormous. On the other hand, the City Planning Act regulates to separate the residential area and industrial area. Therefore, it is difficult to locate non-factory heat consumers, which potentially have a demand for relatively low temperature heat, near power plants. Therefore, creation of heat demand in areas adjacent to the power plants and development of technologies to utilize low-temperature waste heat are needed.

Municipal waste incinerators

Since Japan has little potential landfill site for waste, the volume of waste has long been reduced by incineration and then disposed of in landfills. It is said that more than half of the world's incinerators are located in Japan. The status of the facilities as of FY2020 is as follows:

Total amount of municipal waste:	42 million tons (per person per day: 901 g)
Number of municipal waste incinerators:	1,056 facilities
Rate of facilities with power generation:	36.6%
Total electric power generated:	10,153 GWh

4.1.2 Germany

The use of industrial waste heat offers outstanding energy potential for companies in Germany. For example, German industry uses approx. 1,900 Petajoules of energy input for process heat, or approx. 530 Terawatt hours of energy to generate heat for production and manufacturing processes. However, about 50 % of this is lost as unused waste heat (BMWK, 2021).

At present, however, there are still no comprehensive statistical surveys on current waste heat utilization in Germany. One of the reasons for this is that the temperature levels of the waste heat sources and the types of use (internally in the company, externally e.g. via heat networks etc.) are very different.

More concrete data were available on the feed-in of waste heat into heat networks. In 2018, for example, the share of waste heat from industrial processes in the heat grid feed-in was 1.7%. A survey by the Federal Statistical Office shows that 2,383 GWh of the heat network input in Germany in 2018 was provided by external purchases from industry, which can be assumed to be the use of industrial waste heat in district heating (Steinbach et al., 2021).

In addition, around 5.5 % of district heat (ca. 7,000 GWh/yr) was produced by waste incineration plants in Germany in 2020 (BDEW, 2021); about half of this is counted as renewable energy, based on the composition of the waste. More than half of the district heat supply in Germany is provided by from cogeneration of heat and power, i.e., making use of waste heat from gas or coal power plants. There is also a lot of industrial cogeneration. On the other hand, most of the waste heat from thermal power plants in Germany remains unused (cf. chapter 4.2).

4.2 Potential for Waste Heat Usage

4.2.1 Japan

Waste heat sources

In Japan, about 60% of primary energy is discharged into the environment without being effectively utilized during conversion and utilization. Figure 4.-1 shows the results of a survey of 1,273 business sites in 15 types of energy intensive industries, in terms of the temperature range and amount of heat of exhaust gas, that is waste heat, per business site. Note that only the power industry has a second axis on the right-hand side in Figure 4.-1. Overall, the majority of the waste heat is in the 100-199°C range, and waste heat below 200°C accounts for 76% of the total.

From the power industry, there is a very large amount of waste heat of 1,200 TJ/factory in the 100-149°C range. It is estimated that approximately 260621 TJ/year of waste heat is generated by the power industry in Japan as a whole, of which 186851 TJ/year is waste heat at 100-149°C. Waste treatment industry produces relatively high temperature waste heat with a considerably high amount of heat. The oil/coal and nonferrous metals industries also produce a large amount of waste heat at temperatures of 500°C or higher. Waste heat from the Waste treatment, oil/coal, and nonferrous metals industries are estimated to be about 57942 TJ/year, 44889 TJ/year, and 16367 TJ/year, respectively in Japan as a whole.

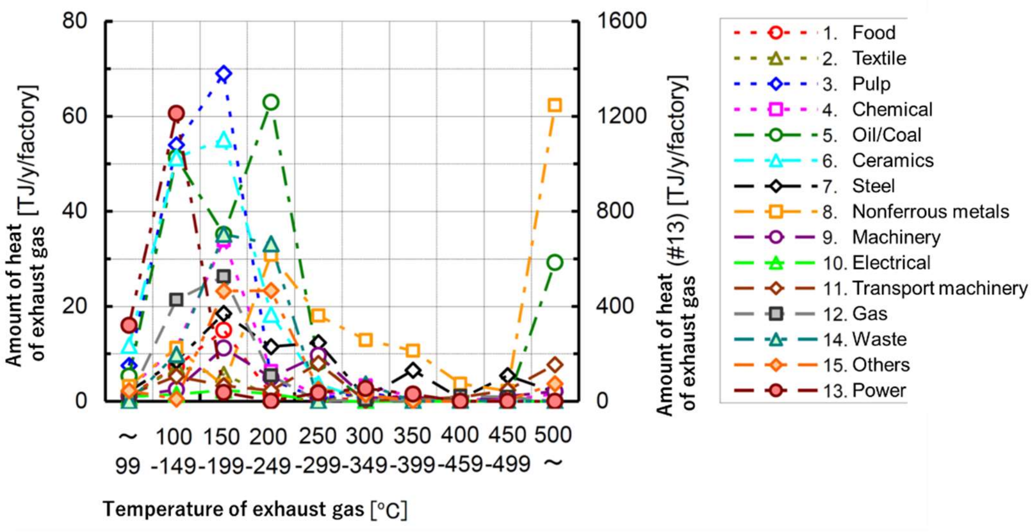


Fig. 6 Temperature and amount of heat of exhaust gas per factory by industry. (TherMAT, 2019)

Potentials for expanded waste heat utilization

Most of heat demand is in a range of above 200°C whereas the potential for waste heat is mainly in a range of below 200°C. Therefore, it would be important to develop technologies to utilize low-temperature waste heat, such as high-temperature heat pumps.

As for relatively high-temperature waste heat, waste heat use within a factory has been progressing, but heat transfer between factories and heat supply to residences has not yet.

For expanding waste heat utilization, it will be important to review regulations regarding factory locations and promote government support.

A promising application for expanded waste heat utilization is using waste heat from data centers. There are initial approaches to the use of waste heat in Japan, and NEDO is now also tendering projects. There are R&D measures and project ideas, e.g. in Hokkaido. Since the climate there is cool, there are many data centers there that use both, cooling power and heat pumps (source: discussion at the German-Japanese Expert Workshop on Industrial Waste Heat Usage (online) with NEDO on April 22nd, 2021).

Municipal waste incinerators

At present, each municipality in Japan is responsible for its own waste. In the meantime, municipalities are starting to join forces and share larger incinerators in order to have a more cost-efficient operation and also generation of electric power. (Source: discussion of ECOS with the Natural Energy Research Center – NERC in Hokkaido, 2023)

Since municipalities operate the incinerators, the main heat utilization is limited to heating and air conditioning in public facilities such as swimming pools, and there are few examples of supply to private sector. The problems with heat utilization are the distance between the incinerators and heat consumers and the fact that it is limited to public utilities. To solve these problems, both technology and municipal policies are needed (MOE, 2022-1).

Sewage treatment facilities

At the sewage treatment facility, the digestion gas (biogas) is generated as part of sewage treatment. Biogas is fed to a combined heat and power plant, which generates heat and electricity. The heat and electricity are mainly used for internal purposes, and it is difficult to generate excess heat in a stable manner except for large facilities. In addition, heat consumers are rarely located near the plant in the most cases, making heat transport difficult. In Japan, where the natural gas pipeline network is less developed than in Germany, there are limited ways to inject biogas into the pipeline. In recent years, in addition to the conversion of sludge into fuel, the heat in the sewage pipes, which is vastly abundant, is being focused on and effectively utilized.

4.2.2 Germany

Waste heat sources: Sector-specific and temperature-dependent averaged waste heat potentials

The following figure shows an overview of the waste heat potentials in Germany. It can be seen very clearly that there is great potential above all in the area of thermal power plants and CHP plants in particular. It should be mentioned here that the potentials of thermal power plants, CHP plants, waste incineration plants and renewable energies (mainly from biomass plants) are purely theoretical potentials. The potential for Industrial Waste Heat utilization is approx. 10 % of the total usable waste heat.

As part of an IREES study, a database from Fraunhofer ISI was expanded and supplemented to include industrial sites with their production volumes and technologies used. The potential amount of waste heat was then calculated from this database using the calculated energy source inputs and efficiencies. Accordingly, the total amount of waste heat from industry in Germany is approx. 51 TWh. A reference temperature of 25°C is used for the calculation. The waste heat from industrial plants that can be used in heat networks amounts to approx. 8 TWh. For this purpose, it was analyzed which waste heat sources are located within a radius of no more than 10 km from an existing heating network. The reference temperature here is 95°C, so that the waste heat can be used directly in the heat network. (Steinbach et al., 2021)

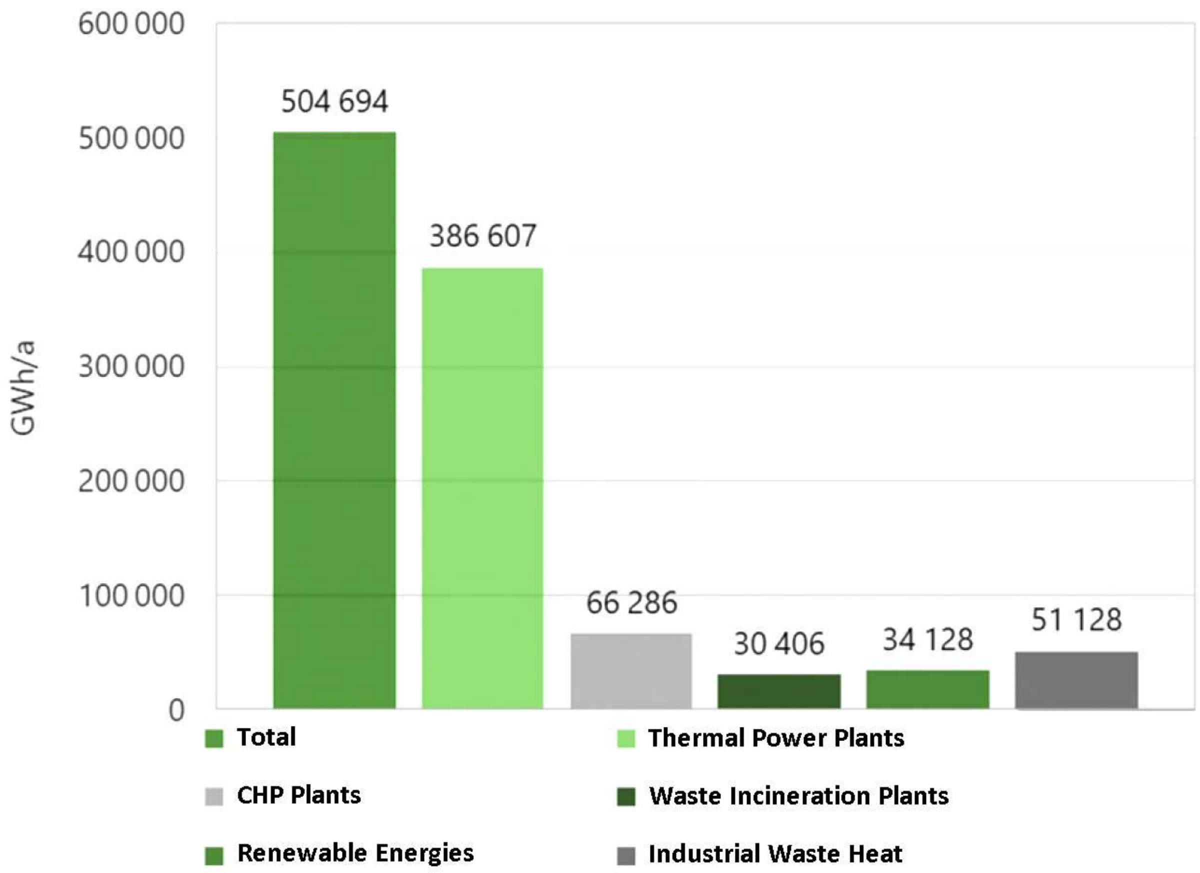


Fig. 7 Potentials of waste heat utilization in Germany (Steinbach et al., 2021)

Potentials for expanded waste heat utilization

The biggest potential for the utilization of industrial waste heat is seen in the iron and steel industry, the chemical industry, the aluminum industry and the mineral industry, especially in the temperature range between 100 and 500 °C. Currently this waste heat is used predominantly internally. However, there is also great potential for future external usage.

Conservative estimates indicate a usable waste heat potential for Germany of at least 12,000 GWh to 70,000 GWh (Steinbach et al., 2021) from various sources that can be harnessed for external use from a technical perspective.

The integration of 70,000 GWh/yr of waste heat for example in district heating networks alone would reduce CO_2 emissions by around 19 million tons per year (AGFW, 2020). This corresponds to around 36% of the reduction target set by the German government in the building sector of 53 million metric tons of CO_2 between 2020 and 2030 (Climate Protection Law 2021). The utilization of waste heat can therefore make a significant contribution to Germany achieving its climate protection targets in the building sector.

In addition, there is probably also substantial further potential for internal use in industry (e.g. power generation) or in industry clusters, by the use of high-temperature heat pumps that can replace other technologies using fossil fuels (e.g. gas boilers). Other promising waste heat sources are sewage water (an example is given in chapter 4.4.2., tab. 4-2) and the utilization of waste heat from data centers. An example is the city of Frankfurt/Main where, for example, the German

Commercial Internet Exchange (DE-CIX) and 60 data centers are located, which together consume 1.6 TWh of electricity. If all their waste heat were used, it would be possible to provide CO_2-neutral heating for all the residential and office space in the Frankfurt City by 2030. Various projects for the use of waste heat from data centers, such as the project in the Westville district with 1,300 apartments, most of which are supplied by data center waste heat, have already started (Datacenter Insider, 2021).

4.3 Policy Measures for Promotion of Waste Heat Usage

4.3.1 Japan

Energy consumption efficiency has improved by 40% since the oil crisis of the 1970s, due to the efforts of the public and private sectors in Japan. The Act on Rationalizing Energy Use was enacted in 1979, and it continues to be revised to the present. Japanese government aims to achieve a more rational energy supply-demand structure by integrating regulatory measures based on the law with budgetary measures and other effective support measures (Strategic Energy Plan, 2021):

Regulatory measures

In 2018, the Act on the Rational Use of Energy was revised to establish a cooperative energy conservation planning system that allows the government to certify and evaluate energy conservation efforts made by multiple businesses in cooperation. The Act on the Rational Use of Energy requires, as an effort target, a reduction in energy consumption intensity or electricity demand leveling assessment intensity (energy consumption intensity plus a factor of electricity purchases during electricity demand leveling hours which is from 8:00 to 22:00 in July to September and December to March) of 1% or more per year on average over the medium to long term. Internal waste heat utilization is one way for a company to achieve this target. In addition, the Benchmark Program is being introduced to set targets for energy consumption intensity by industry sector. This has been introduced in 6 industries and 10 sectors in the industrial sector (METI, 2022).

The Act on Promotion of Global Warming Countermeasures requires entities whose energy consumption or greenhouse gas emissions exceed a certain level to report their energy consumption and greenhouse gases (METI, 2022).

In addition, the Top Runner Program for energy-consuming equipment requires manufacturers to improve the energy consumption efficiency of the equipment they ship. Reducing waste heat that is released from the equipment is one way to achieve this for several types of equipment (METI, 2022).

Financial incentive measures

Financial incentive measures are being promoted in tandem with the aforementioned regulatory measures.

METI (The Ministry of Economy, Trade, and Industry) provides subsidies of 25 to100% of the investment to companies in the introduction of advanced energy-saving equipment, the introduction of various energy-saving facilities, and measures to reduce electricity consumption during peak periods. The budgeted amount is approximately 160 billion yen in 2022FY. Besides, 100 billion yen is contributed to improve the thermal insulation of homes, and 30 billion yen for the introduction of high-efficiency water heaters. In addition, subsidies are provided for Net Zero Energy Building / Net Zero Energy Home and energy-saving renovations, and support is provided for the development of innovative technologies (IEEJ, 2022).

MOE (The Ministry of the Environment) has budgeted more than 10 billion yen per year in total for promoting regional renewable energy and resilience. It includes the projects to support the introduction of facilities that utilize unused local heat, such as heat exchangers, heat pumps, heat pipes, pumps, heat conduits, and thermal storage systems (power generation facilities are not eligible) and subsidizes companies and organizations by 33 to 50% of the investment (MOE, 2022-2, MOE, 2022-3,).

Research and development

Over the past decade, METI and NEDO (New Energy and Industrial Technology Development Organization) have been developing technologies to reduce thermal energy losses, reuse and convert unused thermal energy, and develop thermal management technologies and basic technologies that address these technologies across the board. Reduction technologies include thermal insulation, heat shielding, and thermal storage. Reuse technologies include heat pumps. Conversion technologies include thermoelectric conversion and waste heat power generation. The total budget for FY2013 to FY2022 is approximately 10 billion yen (NEDO, 2022).

4.3.2 Germany

Regulatory measures

Internal use:

On the EU level, the product-specific regulations under the Ecodesign directive set legal requirements for products' circularity, energy performance and other environmental sustainability aspects and creates energy labels that, among others, also include standards for heating and cooling devices (European Commission, 2022).

In addition, the European DIRECTIVE (EU) 2018/2002 of 11 December 2018 on Energy Efficiency regulates, among other things e.g., the mandatory energy management or energy audits for companies that are defined to be larger than small and medium enterprises (European Union "Official Journal of the European Union", 2018), which is transposed in Germany in the energy services law. This helps to identify potential internal uses of waste heat to save energy.

On the national level, a variety of regulations for planning and installation of components are to be complied.

External use:

In general, all guidelines relevant to the transport and use of heat must also be observed for the use of waste heat.

On the national level, the access of third parties (e.g. for the supply of waste heat) to heating networks and infrastructure facilities is currently regulated in Germany in Section 19 of the Act against Restraints of Competition (GWB – "Gesetz gegen Wettbewerbsbeschränkungen"). In addition, guidelines are currently being planned at the EU level that guarantee the feed-in of waste heat:

In the current draft amendment to the Directive on the Promotion of Energy from Renewable Sources (RED II, Art. 24, Para. 4a), the EU Commission stipulates, among other things, that member states must ensure that operators of district heating and cooling systems with a capacity of more than 25 MWth are obliged to grant third-party suppliers of energy from renewable sources and waste heat and cooling access to the grid, or that they must offer third-party suppliers to purchase their heat or cooling from renewable sources or waste heat and cooling and feed it into the grid.

Financial incentive measures

Currently, various programs are in effect in Germany that provide subsidies for waste heat utilization, among other things:

a) Energy and resource efficiency in enterprises

This financial incentive program supports, among other things, measurement and control technology, sensor technology, energy management software, and measures for the use of waste heat in and outside the company. The funding rates are up to 40, 50, or 55 % depending on the subject, and they are higher for SMEs than for large companies (Deller, 2022).

b) Federal funding for efficient heat networks

In force since September 2022:

Module 1 funds up to 50 % of the costs of feasibility studies for the construction of heat grids with a minimum of 75% heat feed-in from RE and unavoidable waste heat, as well as transformation plans with the goal of converting existing heat grids to full supply from eligible renewable heat sources by 2045.

Module 2 supports investment costs for the implementation of new heat networks based on a feasibility study as well as packages of measures for the implementation of a transformation plan for existing networks. The rate of support is 40 %.

Module 3 offers 40% of the investment costs for, among other things, heat pumps, heat storage, pipelines for the connection of RE generators and the integration of waste heat, as well as for the expansion of heat grids and heat transfer stations (Deller, 2022).

c) Waste heat and municipal heat planning

Financial support (currently up to 80%) and technical advice to promote municipal heat planning. Central coordination instrument for the local heat transition to create investment security for the development of infrastructures, especially heat networks, but also gas and electricity networks. The government plans to make such planning mandatory for medium and large municipalities in a few years from now (Deller, 2022).

Barriers for the utilization of waste heat (technological, political and infrastructural)

The existing policy measures listed above already try to tackle the many barriers for the utilization of waste heat. However, further policies and measures may be needed to overcome the barriers discussed below. These are based on experiences and analyses in Germany, but the same, similar, or other barriers may also exist in Japan.

In addition to technological and physical barriers due to the often different temperature levels of waste heat sources and heat sinks, there are also energy and electricity tax barriers to the integration of industrial waste heat into the municipal heat supply.

In connection with industrial waste heat utilization, the following barriers are particularly noteworthy:

Payback periods: The investments for the plant technology for heat recovery sometimes lead to long payback periods. Investments increase especially when special requirements are made regarding temperature and corrosion resistance or when large heat exchangers are needed for low-temperature applications.

Heat partnerships: Further hurdles lie in the design of the heat partnerships between waste heat producing companies (heat source) and heat supply companies (heat sink). As a rule, waste heat projects have a long planning lead time because numerous technical, legal and contractual issues have to be considered and clarified. Due to high investments with long depreciation periods, the business models of district heating companies are usually designed for at least 10 to 20 years. Since industrial companies typically expect much shorter investment cycles and location decisions can be made within a short period of time, there is a potential for conflict and increased uncertainty for district heating suppliers.

Plant size: Larger plants for waste heat recovery tend to be economically more advantageous than smaller plants due to economies of scale.

Availability: If a third-party supplier wants to feed waste heat into heating grids, the amount of heat contractually guaranteed to customers must be secured with non-fluctuating generation capacities. Depending on the design, it may also be necessary for smaller renewable energy or waste heat capacities fed into the grid to be secured by the third-party suppliers in the grid itself (Source: Ortner et al., Umweltbundesamt (German Environmental Agency), 2022)

4.4 Good Practice Examples

This chapter presents a selection of good practice example for the external utilization of waste heat from different sources. There are of course many good practice examples for the internal utilization in industries, but we found it difficult to obtain concrete data on the internal use of waste heat, which may be due to commercial reasons.

4.4.1 Japan

Examples of multiple use of waste heat

Currently, in most cases, the waste heat from power plants, municipal waste incinerators, and sewage treatment facilities is used for on-site use or in nearby public facilities. However, there are also cases where heat is supplied from those waste heat sources to chemical plants and nearby residential areas. Typical examples are shown in Table 4-1.

Heat source	Name/Place	Description	Overview
Power plant	**Kawasaki Steam Net (Kanagawa)**	Steam from the Kawasaki Thermal Power Station is supplied to 10 nearby factories (chemical plants, etc.) located in the Keihin industrial area.	
Municipal waste incinerator	**Hikarigaoka Housing Complex (Tokyo)**	Heat is supplied for heating and hot water supply from the Hikarigaoka municipal waste disposal facility in conjunction with the construction of a large 12,000-unit residential complex.	
	Shinagawa Yashio Housing Complex (Tokyo)	Provides heat for heating and hot water supply to a large residential complex of 5268 units, using waste heat from the incineration plant of the Shinagawa municipal waste disposal facility.	
Sewage treatment facility	**Rokkou Island Housing Complex (Hyogo)**	Rokko Island Energy Service supplies waste heat from the incineration of sludge from the sewage sludge center to nearby housing complexes. Supply conditions are variable depending on the operation of the sludge center.	

Tab. 4 Best Practice Examples of waste heat usage in Japan (Source: ANRE, 2015)

Example of research and development outcomes

As an example of R&D outcomes, a new type of heat-driven chiller with increased thermal efficiency (COP) has been developed to generate cold heat from low-temperature waste heat that could not be used in the past; the chiller recovers heat from 95°C waste hot water to 55°C and generates cold water down to 0-3°C for cooling. It has been installed in buildings, factories, and hospitals in Germany, Poland, and Slovakia.

4.4.2 Germany

Examples of multiple use of waste heat

In most cases only examples for external use of waste heat have been available. Although internal use of waste is already common in many factories, most of them do not publish data about their internal processes and heat fluxes. In Germany there is a growing number of district heating networks using waste heat. Table 4-2 gives some examples for using waste heat from sewage water and industry for urban quarters.

<table>
<tr><th>Heat source</th><th>Name/Place</th><th>Description</th><th>Overview</th></tr>
<tr><td>chemical by-product of copper production</td><td>Industrial heating eastern HafenCity in Hamburg*</td><td>Heat is supplied for an urban quarter. The heat supply comes from a chemical by-product of copper production at Aurubis (copper production). A 2.7-kilometer-long heat transport pipeline connects the eastern HafenCity with the Aurubis plant. There, it is fed into district heat supply network of the utility company “enercity” a municipal energy supply and service company. The pipeline for heat transport is designed for a capacity of up to 60 MW, which is the total potential of the Aurubis industrial waste heat.</td><td>

Area of copper factory Aurubis and HafenCity in Hamburg*</td></tr>
<tr><td>Waste heat from sewage</td><td>'Neckarpark' quarter in Stuttgart**</td><td>Heat from a sewage system is supplied for heating and hot water supply for a quarter in Stuttgart. Since 2020, heat has been supplied to the first three connected buildings,
In the following years, the number of heat consumers will gradually increase to around 850 residential units and commercial areas.
The heat exchanger is developed for retrofitting of existing and new sewers in a modular design and can be positioned using the existing manhole structure. Due to the modular concept the heat exchanger can be extended any time.
In addition, the heat supply system contains a heat pump with an output of approx. 2.9 MW and a COP of approx. 3.45, as well as a CHP unit and a peak load boiler to cover peak loads on particularly cold days.
The energy demand of the heat pump is partly provided by a PV system installed on the buildings in the district. The entire plant went into operation in September 2020.</td><td>

Heat exchanger for sewage water**</td></tr>
</table>

Tab. 5 Best Practice Examples of waste heat usage in Germany

*(*Sources: Elbe Wochenblatt (2018); Aurubis (2022), Ch. Hein, presentation at the waste heat symposium “BMWK-Fachtagung „Klimaschutz durch Abwärmenutzung“ in Hamburg)*

*(**Sources: “Energie Wende Bauen “– Portal for energy-optimized buildings and neighborhoods, 2021; Stadt Stuttgart; “Neckarpark: Neuer Platz für Wohnen und Gewerbe“, 2021; Uhrig Energie GmbH, 2021)*

5 Conclusion: Suggested Priority Research Fields for German-Japanese Cooperation

Several German-Japanese workshops such as "Industrial Waste Heat Usage - German-Japanese Expert Workshop 2021" (online event from April 19-22, 2021) and bilateral exchanges such as the GJETC have identified a whole range of potential areas of cooperation that can subsequently be further developed in collaborative projects. These include, for example

- Optimization of thermoelectric generators (efficiency, materials, production costs, applications),
- Increasing efficiency and demonstrating possible applications for industrial heat pumps such as in the food industry,
- Use of waste heat in data centers
- Use of waste heat from waste water
- Concepts for (municipal) heat networks
- Methods for developing waste heat registers and local heat planning.

From the analysis of framework conditions, available waste heat sources and sinks, as well as the current state and trends of waste heat utilization, the following can be identified as priority research fields for a German-Japanese cooperation:

Framework conditions and policy

Promote analysis of waste heat utilization potential:

An important step is to identify existing usable waste heat potential and the opportunity to promote Energetic Neighborhoods. This includes identifying both the potential "providers" of waste heat, i.e. location/temperature/quantity and temporal availability of the waste heat, and the potential users and their requirements. In Germany, there are now numerous providers of waste heat mapping on the market whose services and know-how could also be used in Japan.

Based on these measures, waste heat producers could be encouraged to disclose their potentials and offer them for use to potential customers, especially district heating companies. This may be combined with an obligation on the part of district heating companies to feed in waste heat if this is economically viable. In addition, subsidies for various systemic measures and technologies such as heat networks, heat storage, heat pump technologies and potential studies would be desirable, like they are already available in Germany. Japan not only relies on the proven "Toprunner" program for equipment and components, but also obliges companies to submit regular reports and take measures to continuously increase energy efficiency in production, which also includes operational waste heat utilization.

Both countries, Germany and Japan, have already launched various subsidy programs to support the use of waste heat. An exchange of experience on the individual effects of the subsidy programs would be desirable here.

Market Design:

In both countries, Germany as well as Japan, large-scale "waste heat markets" do not yet exist; in contrast to the electricity market, there is no free market for heat, including waste heat. Political action is needed on both sides to support the creation of a “waste heat market”, potentially as a part of a wider sustainable heat market.

Infrastructure:

While in Germany mainly district heating grids exist or are also being expanded, this is only common in the very Northern part in Japan. On the other hand, Japan already has longer experience in the construction and operation of cooling systems. An intensified bilateral exchange with regard to technologies (e.g. chillers, heat pumps, energy storage, etc.) and systemic concepts (e.g. heating and cooling networks) could enable further synergy effects for industry, research and (funding) policy for both countries.

A positive example is currently the internal heat infrastructure in chemical parks or steel plants that generate waste heat internally and use it in other production areas. A joint waste heat project, e.g. involving industry (as a potential supplier of waste heat) and municipalities as users, could be beneficial for both sides (Japan e.g. as a supplier of heat pumps or chiller technology, Germany in the area of systemic technology of heat networks and heat storage).

An important challenge in Germany is the gradual decarbonization of existing district heating infrastructure. The injection of industrial waste heat, the use of deep geothermal energy or the conversion to "cold" heat networks (with temperatures of 30°C and less) in which the inclusion of low temperature waste heat sources (e.g. waste water or waste heat from data centers) is currently being discussed. Here, too, bilateral cooperation in research as well as in industrial or municipal applications would make sense.

Technologies

Industrial heat pumps:

Especially in Germany, certain industrial sectors are affected by high energy costs (e.g. natural gas). The substitution of fossil fuels with hydrogen will take a longer period of time in most cases, but many sectors, such as the food industry, need short- or medium-term solutions in order to continue to produce economically. Heat pump technology is capable of closing heat cycles and replacing fossil fuels in the medium term by using operational waste heat at different temperature levels. Here, cooperation between German and Japanese research institutes and heat pump manufacturers for the further development and use of heat pumps (also in the high-temperature range of 120°C and more) and users would make sense.

Heat storage

Heat storage is an important component in waste heat utilization and distribution.

Besides classical methods of heat storage via liquid storage media, solid media are also well suited to store waste heat without heat loss over a longer period of time or to reuse it in the short term. Especially in the field of phase change materials (PCM) for latent heat storage, Japan has numerous research and development results that could also be helpful for German industry or municipal waste heat utilization within the framework of a joint bilateral project.

Thermoelectric generators (TEG)

Here, both the German and Japanese sides are working on further development of the systems. A possible interface for installation here would be, for example, integration into an heat exchanger as an intermediate layer. In both countries, there is potential for the application of TEG, but the conversion efficiency of approx.. 5-7 % for electricity generation from heat is not very high. However, TEGs have the operational advantage over other methods of generating electricity from heat, such as ORC plants, in that they can be used for both continuous and discontinuous waste heat generation even with relatively small temperature differences. In addition, TEGs can also be used for cooling, as is the case with heat pumps. Japan has already made considerable progress in this area, for example in the cooling of LEDs in telecommunications equipment.

In Germany, there is still a need to catch up here, which means that cooperation in the research and application sectors is particularly recommended. In this field, a cooperation between a Japanese company and a German research institute has already been established as a follow-up to the German-Japanese workshop "Industrial Waste Heat Usage - German-Japanese Expert Workshop 2021".

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German Japanese Energy Transition Council

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Comparing the Basic Strategies of Japan and Germany Against the Energy Crisis While Aiming to Achieve Their Climate Mitigation Goals

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List of Abbreviations, Units and Symbols

Abbreviations

BMBF	German Federal Ministry of Education and Research
BMU	German Federal Ministry for the Environment, Nature Conservation, Building and Reactor Safety
BMVI	German Federal Ministry of Transport and Digital Infrastructure
BMWi	German Federal Ministry for Economic Affairs and Energy
BMWK	Ministry of Economics and Climate Action
CCUS	Carbon Capture, Utilization and Storage
CE	Circular economy
CNG	Compressed natural gas
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilization
DAC	Direct air capture
EEG	Energy Efficiency Law
Fig.	Figure
FSRU	Floating Storage and Regasification Unit
GEG	Buildings Energy Law
GHG	Greenhouse gas
GJETC	German Japanese Energy Transition Council
GW	Gigawatt
GWP	Global warming potential
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IRA	Inflation Reduction Act
ISO	International Organization for Standardization
LCA	Life-cycle assessment
LNG	Liquefied natural gas
LPG	Liquefied Petroleum Gas
Max	Maximum
Min	Minimum
NDC	National Determined Contribution
R&D	Research and development
SES	System Development Strategy
Tab.	Table
WI	Wuppertal Institut für Klima, Umwelt, Energie GmbH

Units and Symbols

$	US dollar
%	Per cent
€	Euro
°C	Degrees Celsius
Ag	Silver
Al	Aluminium
Au	Gold
bn	Billion
CO_2	Carbon dioxide
CO_2 eq.	Carbon dioxide equivalents
Dy	Dysprosium
g	Gram
Gt	Giga tonne
GW	Gigawatt
h	Hour
H_2	Hydrogen
H_2O	Water
In	Indium
kg	Kilogram
km	Kilometre
kt	Kiloton
kW	Kilowatt
kWh	Kilowatt hour
l	Litre
Li	Lithium
m	Million
MJ	Megajoule
Mt	Metric tonne
MW	Megawatt
Nd	Neodymium
Nm^3	Normal cubic metre
p.a.	per annum
PJ	Petajoule
pkm	Passenger kilometres
ppm	Parts per million
s	Second
t	Tonne
TWh	Terawatt hour
vol%	Percentage by volume

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1 Executive Summary

This paper compares the climate protection strategies of Japan and Germany in the context of the energy crisis triggered by the Russian invasion of Ukraine. It examines whether, and if so, how previous climate protection goals and strategies have been altered by the energy crisis, particularly with regard to security of supply and the mitigation of price effects.

Japan has set a goal of reducing greenhouse gas emissions in 2030 by 46% from 2013 levels. It has also made an international pledge to achieve a carbon neutral society by 2050. Germany aims to be greenhouse gas-neutral in less than 25 years – in 2045 at the latest. It also targets for electricity supply in 2030 to be based on 80% of renewables.

On the way to carbon neutral societies Germany and Japan have many common, but also differentiated challenges to be solved. Both countries have low energy self-sufficiency rates. Therefore, the path to a carbon-neutral society must strengthen the national energy sovereignty. Especially with the experience of the current energy crisis, this means that the *national* potentials for energy and resource efficiency and renewable energy sources should be exploited as much as feasible with highest priority. Japan places the highest priority on energy conservation and renewables, just like Germany. But by considering short-to mid-term necessity of fossil fuels and challenges of significant improvement of energy efficiency and limited potential of renewable supply, Japan is also planning to continue using fossil fuels directly (with CCUS) or through imports of blue hydrogen or ammonia, and therefore needs a strong “decarbonization of fossil fuels” strategy. In addition, Japan seeks for utilizing nuclear power as a substitute for fossil power generation. Germany (like the EU) is more focused on the accelerated reduction of fossil fuels by renewables and energy conservation. Induced by the energy crisis, In Germany and the EU, the ambition in the targets for energy efficiency and renewables has even been increased, aiming for synergies between energy sovereignty and climate mitigation. However, on the other hand, steps have been taken for the massive expansion of LNG terminals and for diversification activities with regard to fossil energy supply sources, which raise questions of climate-relevant lock-ins and of compatibility with the climate protection goals.

On the surface, the strategies of Japan and Germany appear to be very different, but it could be argued that, in reality, there are more common challenges. Firstly, both countries put priority on energy and resource conservation as well as the supply of renewable energy sources. Secondly, both need to use fossil fuels as a transitional pathway to a carbon neutral society, and thus have to take actions to ensure security of supply. One difference may lie in whether or not there is confidence for building the future energy system completely based on energy conservation and renewable energy, and hence the duration of the use of fossil fuels as a transitional pathway. This different perspective may be due to the geographical and geopolitical conditions in which both countries find themselves. With regard to current policy priorities, there is a clear difference concerning the role of nuclear energy.

Questions remain on the one hand as to whether and how Germany (the EU) can achieve the ambitious climate protection goals primarily based on renewable energies and energy efficiency under changed geostrategic conditions. On the other hand, Japan faces the challenge of how to develop a decarbonization path under the special conditions of an island state that generates minimal risks in the long term and is prepared for the competition on global GreenTech lead markets for renewables and energy efficiency.

2 Japan: Combining Efforts to Reduce and to Decarbonize Fossil Fuels

2.1 Fossil Fuel Situation in Japan

Japan has set a goal of reducing greenhouse gas emissions in 2030 by 46% from 2013 levels. It has also made an international pledge to achieve a carbon neutral society by 2050. Japan, like other countries, is taking national measures to address climate change.

However, the energy situation has changed drastically since the 2011 Great East Japan Earthquake shut down nuclear power generation, the economic stagnation caused by the spread of coronavirus infection that has continued for the past three years, and the Russian invasion of Ukraine that began in February 2022. In addition, Japan has not made enough progress in creating an environment for electricity deregulation, developing a grid to actively introduce renewable energy, and restarting nuclear power plants.

To begin with, Japan, surrounded by the sea and lacking its own energy resources, relies on imports of fossil resources and fuels from overseas. As a result, Japan is very sensitive to sudden changes and fluctuations in energy supply and demand.

As an aside, Japan used to mine coal and other resources domestically. Due to rapid economic growth in the 1970s and the expansion of imports of cheap energy resources from abroad, the domestic supply of energy resources has gradually shrunk and is now almost non-existent. Therefore, it was necessary to import high-density energy resources to Japan with high efficiency, and more than 50 years ago, the world's first project to liquefy and transport natural gas was successfully completed. Since the arrival of a 30,000-ton liquefied natural gas (LNG) carrier from Alaska to Japan in 1969, this marine transportation of energy by LNG has now become a global standard.

Incidentally, Japan's energy self-sufficiency rate is only about 12%. Figure 2-1 compares the primary energy self-sufficiency ratios among major nation. In Japan it is very low compared to other developed countries, and it is only about 1/3 of the self-sufficiency rate of Germany (about 35%).

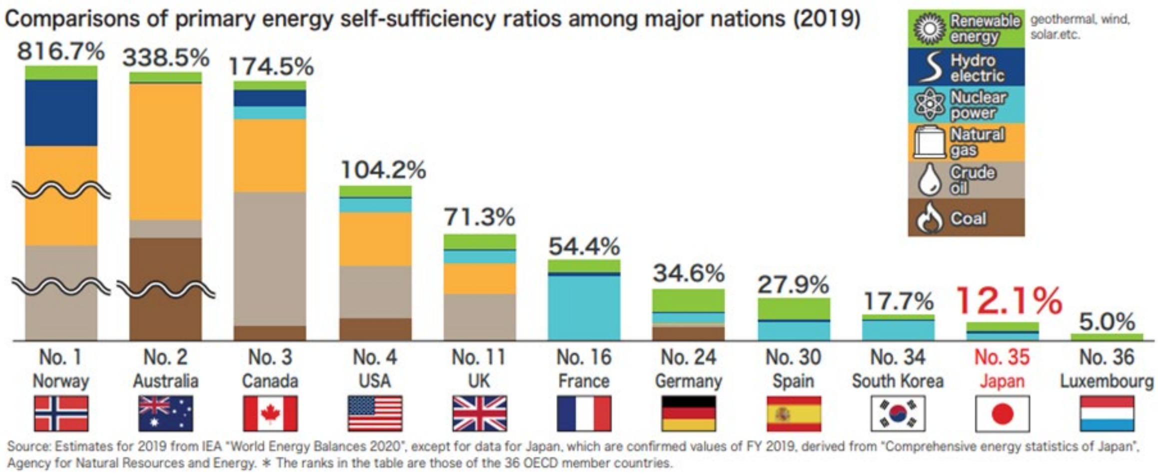


Figure 2-1 Comparison of primary energy self-sufficiency ratios among major nations

(Source: METI)

Therefore, Japan is sensitive to the world's energy situation. In other words, just like other countries and due to the global energy crisis around the world, Japan is experiencing a tight power supply and demand situation and energy prices are increasing. This means that Japan is facing an energy crisis comparable to the oil crisis that occurred in Japan in 1973. The recurrence of such an energy crisis demonstrates the fragility of Japan's energy supply system and the issues of energy security. This is a critical issue because ensuring a stable energy supply is fundamental to people's lives and corporate activities. In this point of view, Japan is promoting thorough energy conservation, structural transformation of the manufacturing industry (fuel conversion and raw material conversion), active introduction of renewable energy, utilization of nuclear power, promotion of introduction of CO_2-free fuels such as hydrogen and ammonia, strengthening of international cooperation to secure resources and energy, and promotion of carbon recycling and CCS introduction. Please add a short remark whether these strategies are accelerated by the current energy crisis.

2.2 Energy Structure in Japan

As described earlier, Japan relies on imports from abroad for most of its primary energy. Figure. 2-2 shows energy flows in Japan. The values on the left side of the figure show the energy supply but it can be seen that oil, coal, and natural gas supply almost all of it.

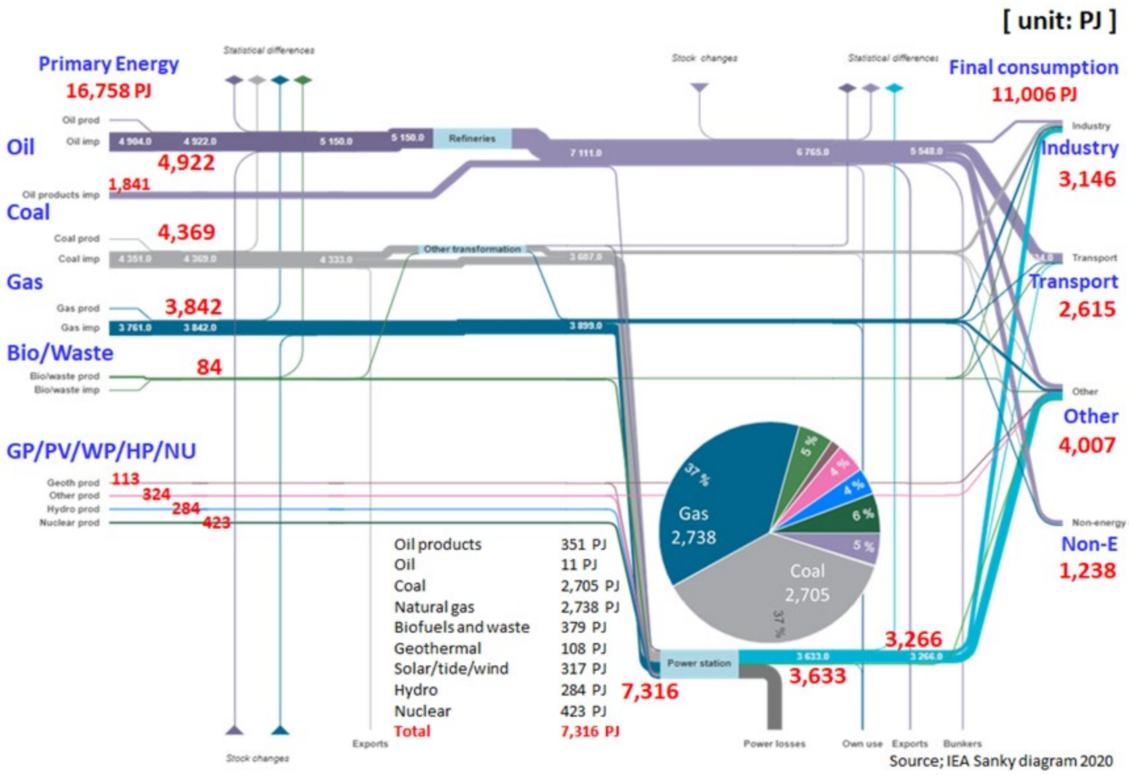


Figure 2-2 Energy flow in Japan

(Source: IEA Sankey Diagram 2020)

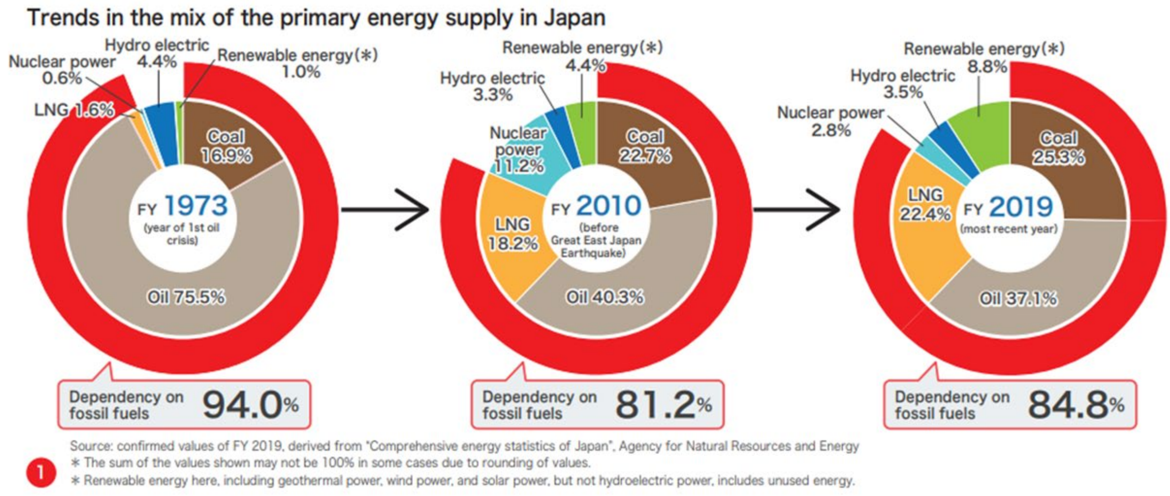


Figure 2-3 Trends in the Mix of the Primary Energy Supply in Japan

(Source: METI, 2022)

For clarity, the primary energy source is depicted in a pie chart in Figure. 2-3 Until the Great East Japan Earthquake in 2011, the country had actively promoted the introduction of nuclear power and renewable energy in order to reduce its dependence on fossil resources and fossil fuels, but since the earthquake, the country's dependence on fossil resources (fuels) has increased again.

Primary energy consumption in Japan is approximately 17,000 PJ as shown in Figure. 2-2. Of this primary energy source, oil, coal, and natural gas account for about 85% and are sources of CO_2 emissions. Of this primary energy, about 7,300 PJ (about 43%) is consumed for power generation. And fossil fuels account for about 80% (about 5% oil, 37% coal, and 37% natural gas) of the fuels used for power generation. Renewable energy, including hydropower, accounts for about 12%. Approximately 7,300 PJ of energy supplied to the power plant is converted into electricity, which is then supplied to the industrial, transportation, and consumer (household and business) sectors as approximately 3,300 PJ of electricity. This means that the power generation conversion efficiency is about 45% on average. Of the approximately 17,000 PJ of primary energy, approximately 9,700 PJ of energy not used for power generation is consumed in the industrial, transportation, and consumer sectors as raw materials for products, fuel for manufacturing, and heat sources. The amount of energy consumed in the industrial, transportation, and consumer sectors is 3,146 PJ, 2,615 PJ, and 4,007 PJ, respectively.

Renewable energy is an essential tool for decarbonization, but the energy structure of Japan shows that renewable electricity alone is not enough to decarbonize the country. In other words, even if all electricity is supplied by renewable energy sources, it represents only 30% of primary energy as shown in Figure. 2-2 The remaining 70% are raw materials and fuels derived from oil, natural gas, and coal. This is where CO_2-free raw materials and fuels must be supplied.

Please refer to the GJETC scenario comparison and the restrictions to use existing renewables potentials in Japan.

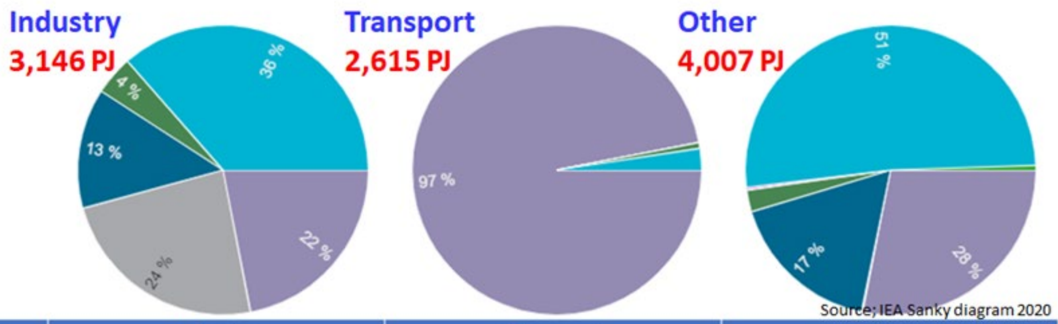
There is a limit to the amount of renewable energy that can be introduced in Japan. Japan has few flat lands and limited areas with good wind conditions. Many areas on the Sea of Japan side of the country have large amounts of snowfall, making them unsuitable for solar and wind power generation. In addition, suitable locations for renewable energy are unevenly distributed in regional areas and are distant from densely populated areas (energy-consuming areas). This means that large-scale reinforcement of power transmission and distribution facilities will be necessary.

Policies are underway in Japan for the active introduction of offshore wind power generation. Japan does not have as much suitable shallow water as Europe, and is hit by typhoons and other storms, making it difficult to introduce wind power quickly and in large quantities. Of course, it also takes time to obtain the consent of local fishery associations and residents.

Therefore, in the future, the policy must be promoted with a view to importing renewable energy. Therefore, various methods are currently being considered in Japan. Hydrogen, ammonia, methanol, and MCH are being considered as energy carriers.

2.3 Energy Usage by Sector and Directions for Decarbonization

The different sectors use energy in very different ways. Figure. 2-4 shows a breakdown of energy consumption in each sector. This figure shows that the transportation sector is dependent on gasoline and other petroleum products. On the other hand, it can be seen that the consumer sector (other section in Figure. 2-4) is the most electrified. The industrial sector is very complex due to the mix of various industries. In this way, there is no general solution for all sectors toward carbon neutrality (decarbonization).



Source	Industry	Transport	Other
Oil products	689 (22%)	2,534 (97 %)	1,126 (28%)
Coal	748 (24%)		5
Natural gas	424 (13%)	1	688 (17%)
Bio/waste	140	18	94
Geothermal			5
PV/tide/WP			7
Electricity	1,145 (36%)	62	2,059 (51%)
Heat			23
Total	3,146	2,615	4,007

Figure 2-4 Energy consumption for each sector in Japan

(Source: IAE created from IEA Sanky diagram 2020)

2.3.1 Transport sector

The transport sector is heavily dependent on gasoline and other petroleum products, which account for 97% of the total as shown in Figure. 2-4. In other words, the key to decarbonizing the transport sector is how to replace these petroleum products with CO_2-free fuels. The solution would be to introduce zero-emission vehicles such as electric vehicles and fuel cell vehicles. However, although Japan is also actively introducing electric vehicles, they account for only about 2% of electricity consumption. Further introduction of electric vehicles would be desirable.

On the other hand, the introduction of electric and fuel cell vehicles, of course, requires the supply of electricity and hydrogen. As an extreme example, if all internal combustion engine vehicles running in Japan were replaced with electric vehicles, how much electricity would be required? The number of automobiles running in Japan is approximately 80 million. Automobile fuel can be broadly divided into three types: gasoline, diesel fuel and LPG (Liquefied Petroleum Gas). The fuel consumption and vehicle mileage for each are compiled by the Japanese Ministry of Internal Affairs and Communications[1]. Although the details of the calculation are omitted, the amount of electricity required for electric vehicles can be calculated from Ministry of Internal Affairs and Communications data to be approximately 100 billion kWh (about 380 PJ). If this amount of electricity were to be supplied by photovoltaic power generation approximately 100 GW of solar panels would be required, assuming that the annual installed utilization rate of photovoltaic power generation in Japan is approximately 12%. This capacity of photovoltaic power generation is approximately 1.5 times greater than the amount of installed capacity that currently exists in Japan. Similarly, if internal combustion engine vehicles were replaced by fuel cell vehicles, about 5 million tons (55 billion Nm3) of hydrogen would be required. Please refer to GJETC scenario comparison up to 2050. It is impossible to procure such quantities of electricity and hydrogen right now. But this impact must be remembered. It will take a very long time to realize such a society, and how to obtain electricity and hydrogen cheaply and in large quantities will be very important in the future.

Incidentally, the Japanese government has set a goal of 100% electric vehicles in new passenger car sales by 2035[2]. With regarding hydrogen, the goal is to introduce up to 3 million tons of hydrogen by 2030, and about 20 million tons by 2050[2].

Another method is to use synthetic fuels that can be produced from biomass, waste cooking oil, and carbon dioxide. However, if synthetic fuels are produced from CO_2 and used, and if the CO_2 source is fossil fuels, then new strategies will be needed to achieve decarbonization, such as utilizing technology to capture CO_2 from the atmosphere (DAC).

2.3.2 Consumer (household and business) sectors

The consumer sector is the most electrified. Therefore, the fastest way to achieve decarbonization in this sector is to make electricity CO_2-free, i.e., to introduce renewable energy. However, as noted

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[1] Ministry of Internal Affairs and Communications, "Automobile Fuel Consumption Survey", https://www.mlit.go.jp/k-toukei/nenryousyouhiryou.html

[2] METI, "Green Growth Strategy Through Achieving Carbon Neutrality in 2050", December 25, 2020.

earlier, there is a limit to the amount of renewable energy that can be introduced, so energy imports from overseas will be inevitable in the future.

All-electric houses and buildings exist in Japan. However, the recent Russian invasion of Ukraine has resulted in an insufficient procurement of fuel for power generation, causing electricity prices to increase sharply. This makes it difficult to keep warm, especially in all-electric homes, as the utility costs are a financial pressure on the family budget. Even if renewable energy is imported from overseas in the future, we must aim to minimize these price fluctuations and ensure a stable power supply. In addition, since renewable energy is an unstable power source that is affected by weather conditions and other factors, the strategy will need to include the introduction of energy carriers and the operation of nuclear power.

Non-electricity energy is mainly oil and gas, most of it consumed for heating purposes. The introduction of CO_2-free fuels is essential to decarbonize oil and gas products. As discussed in the transport sector, synthetic fuels from biomass, waste cooking oil, and carbon dioxide are the most likely candidates.

The spread of energy-complete buildings such as ZEB and ZEH is also important for decarbonization. In Japan, the Sixth Basic Energy Plan sets a goal of ensuring that new houses and buildings constructed after 2030 have ZEH/ZEB level energy efficiency and conservation performance.

2.3.3 Industrial Sector

The industrial sector is a mixture of various sectors, and different sectors use fossil fuels in different ways. In the field of steelmaking, the blast furnace/converter method is the dominant method in the world, accounting for approximately 70-80% of crude steel production. However, the blast furnace/converter method consumes a large amount of coal-derived coke, resulting in high CO_2 emissions. In order to reduce coke consumption, the introduction of hydrogen-reduced steelmaking and direct-reduced steelmaking is under consideration.

In the hydrogen reduction steelmaking process, the reduction reaction with hydrogen is an endothermic reaction, which means that a large amount of hydrogen cannot be supplied to maintain the temperature in the furnace. Of course, there is also the issue of how to obtain hydrogen. In the direct reduction method, iron ore is reduced in solid form using natural gas, etc., and then transferred to an electric furnace for further processing. This method does not use coke, thus reducing CO_2 emissions. However, electric furnaces used in post-processing are more difficult to remove impurities than blast furnaces, and low-grade iron ore with high impurities content cannot be used. Another disadvantage of this method is that it is less energy efficient than the blast furnace method because iron ore reduction cannot be performed in a single furnace. In addition, the advantage of steelmaking in areas where natural gas is cheaply available should not be overlooked. Nevertheless, the direct reduction method has already been introduced in the world and is a promising method for the future. The electric furnace method is attracting worldwide attention because it does not require a reduction reaction and can drastically reduce CO_2 emissions. It is said that CO_2 emissions can be reduced to 1/3 compared to the blast furnace method. In the electric furnace method, scrap iron generated in the city or in steel mills is collected and used as a source of iron. Since the sources of steel scrap in the city are dispersed, there is a need to recover steel scrap in a stable and efficient manner. Scrap iron is already component-adjusted. Therefore, it is not suitable as a raw material for products that require processability and strength. The electric furnace method, which does not use fossil fuels, is the most promising method for decarbonization, but as already mentioned, stable availability of steel scrap and electricity supply are important issues. Instead of natural gas used in direct reduction, synthetic fuels produced from CO_2 and ammonia are candidates for reductants, but the technology is not yet mature.

The cement production process emits a large amount of CO_2 during clinker calcination. In other words, limestone and clay are calcined at 1400° C or higher to produce clinker, and a large amount of CO_2 is emitted during this process. Therefore, CO_2 emissions can be reduced by using CO_2-free raw materials in place of limestone. If CO_2 can be separated and recovered from factory exhaust gases to produce calcium carbonate, it can be used as a raw material to replace limestone, thereby reducing CO_2 emissions. There are also other methods. After cement is produced from clinker, water and aggregate are mixed to produce concrete, but there are other methods of fixing CO_2 in concrete by using new materials that utilize CO_2 in the aggregate. Furthermore, in order to control the strength of concrete, CO_2 is absorbed in the concrete (curing process), and if CO_2 recovered from factory exhaust gas is used for this CO_2, it can contribute to CO_2 reduction.

Thus, when CO_2 is used in the cement production process, the process is simpler because, unlike the production of synthetic fuels and chemicals from CO_2, hydrogen is not needed at all. The Japanese government's carbon recycling technology roadmap published in 2019 (revised in 2021) also clearly states this and sets a high priority for its introduction as a CCU product. However, the heat source (fuel) used for clinker firing, etc. is a fossil fuel, and decarbonization of the heat source must be considered separately. The same argument can be made in the chemical industry (petrochemicals) as in the steel and cement sectors. Since the sources of CO_2 emissions in this field are electricity, raw materials, and heat source (steam), they should be CO_2-free. Of these, electricity and heat source (steam) are related to fossil fuels.

As we have mentioned many before, the use of renewable energy is essential for the decarbonization of electricity. However, the amount of renewable energy introduced in Japan is limited, and the development of transmission and distribution networks for renewable energy has lagged. Therefore, the use of non-renewable energy sources and CO_2-free fuels to supply electricity is also being considered. Of course, this is not limited to the chemical industry. These are solid fuels using biomass and waste plastics, liquid fuels using energy carriers such as hydrogen, ammonia, MCH, and methanol, and gaseous fuels using biogas and synthetic methane. However, CO_2 is generated during fuel production and combustion of energy carriers (during power generation). Therefore, it is necessary to introduce the concept of carbon recycling by, for example, recovering the CO_2 and producing the fuel again.

There are three ways to decarbonize heat: (1) effective utilization of unused heat (waste heat), (2) CO_2-free heat sources, and (3) use of electric heat conversion. Even though waste heat is generated as a by-product in almost all technical processes, it is often lost without being utilized. Waste heat is readily available, but the balance between waste heat sources and consumers is very important. In particular, it is necessary to investigate the temperature range, heat content, waste heat flow, timing of heat supply and heat demand, type of heat medium, and local conditions. Effective use of unused heat (waste heat) can significantly reduce fossil fuel consumption and CO_2 emissions.

However, as long as fossil fuels are used as heat sources, CO_2 emissions cannot be reduced to zero. Therefore, replacing natural gas, light oil, and heavy oil used as heat sources with CCU fuels is expected to significantly reduce CO_2 emissions from heat sources. However, to decarbonize, the CO_2 emitted after combustion (steam production) of the CCU fuel must be recovered. This would not be the case if the CO_2 recovered by DAC is used to produce fuel. Alternatively, CO_2 could be captured by CCS.

As for the electrification of heat using electrothermal conversion technology, it is seen only in small-scale applications. If it is to be made large scale, there are still major issues to be solved, such as securing large scale electricity from renewable energy sources.

2.4 Policy Trends in Japan

The Japanese government announced the 6th Basic Energy Plan in 2021[3]. It sets targets for domestic energy supply and demand necessary to achieve Japan's GHG emissions reduction target for 2030. Figure. 2-5 shows the target power source composition for Japan in 2030 (right side in Figure. 2-5). According to this, the expected electricity supply in 2030 is 934 billion kWh, and renewable energy sources are expected to account for 36-38% (336~353 billion kWh) of this amount. In addition, the goal is to generate 1% of the total amount of electricity generated by hydrogen and ammonia as energy carriers (approximately 9 billion kWh).

Targets for hydrogen and ammonia are described in the Green Growth Strategy[4] released by the Japanese government in 2021, which includes targets for their introduction. Hydrogen is targeted to be introduced up to 3 million tons per year in 2030 and about 20 million tons per year in 2050. Ammonia demand in Japan is expected to be 3 million tons per year in 2030 and 30 million tons per year in 2050. For synthetic methane, similarly, targets have been set in the Green Growth Strategy. According to the strategy, the goal is to inject 1% of synthetic methane into existing infrastructure by 2030 and 90% by 2050. The supply of synthetic methane in 2050 would thus be equivalent to approximately 25 million tons. To achieve these goals, public-private councils[5] [6] [7] [8] have been established to create incentives for businesses formulating a supply chain as soon as possible, and active discussions are still taking place.

3 METI, https://www.meti.go.jp/english/press/2021/1022_002.html

4 METI, "Green Growth Strategies Associated with 2050 Carbon Neutrality", 2021.6., https://www.meti.go.jp/english/press/2021/0618_002.html

5 METI, "Methanation Public-Private Council", https://www.meti.go.jp/shingikai/energy_environment/methanation_suishin/index.html, (Japanese).

6 METI, "Public-private sector council to promote the introduction of synthetic fuels (e-fuel)", https://www.meti.go.jp/shingikai/energy_environment/e_fuel/index.html, (Japanese).

7 METI, "Public-Private Council to Promote the Introduction of Sustainable Aviation Fuels (SAF)", https://www.meti.go.jp/shingikai/energy_environment/saf/index.html, (Japanese).

8 METI, "Public-Private Council for the Introduction of Fuel Ammonia", https://www.meti.go.jp/shingikai/energy_environment/nenryo_anmonia/index.html, (Japanese).

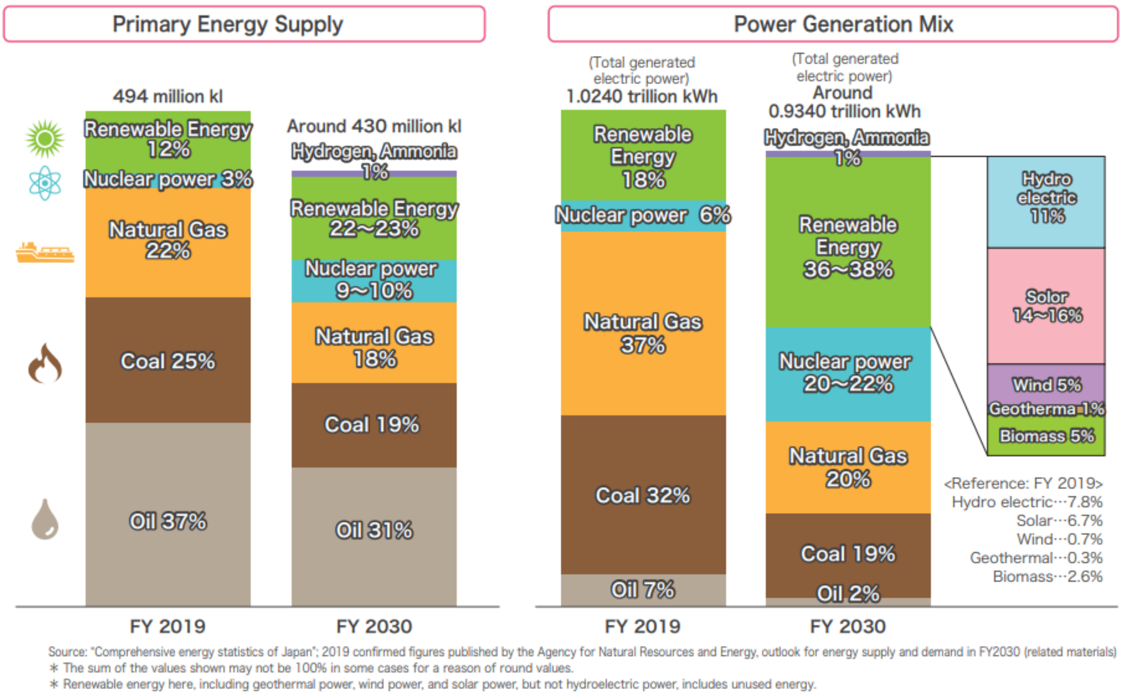

Figure 2-5 Primary energy supply and Structure of power sources in 2030 in Japan

(Source: METI, https://www.enecho.meti.go.jp/en/category/special/article/detail_171.html)

The roadmap for carbon recycling technology was established in June 2019. Subsequently, it was revised in July 2021 due to rapid progress in R&D aimed at international collaboration and the positioning of carbon recycling as a key technology for achieving carbon neutrality in the "Green Growth Strategy Accompanying Carbon Neutrality in 2050" in 2021. Figure. 2-6 shows the carbon recycling technology roadmap.

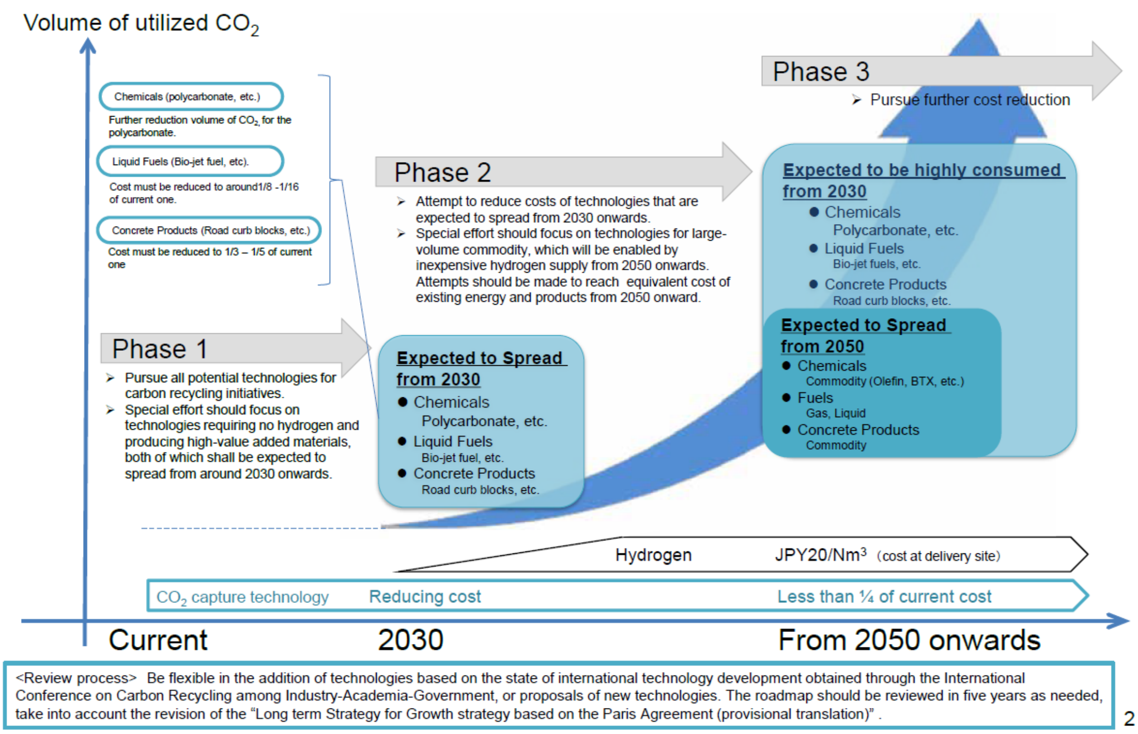

Figure 2-6 Roadmap for Carbon Recycling Technologies

(Source: METI, "Roadmap for Carbon Recycling Technologies", 2019.6)

While the effort toward decarbonization was accelerating, Russia invaded Ukraine. In the long term, improving energy self-sufficiency through energy conservation and renewable energy will be central to countermeasures in terms of both energy security and climate change, and Japan also has a policy to pursue it. However, it will take a long time to realize because it will involve structural changes, thus it will not be sufficient in terms of time horizon of the crises we are facing now. Under such circumstances, the most immediate option that Japan can actually take is to restart existing nuclear power plants. Restarting one nuclear power plant (approximately 1 GW) can reduce annual LNG imports by approximately 1 million tons. Against this background, in August 2022, Prime Minister Kishida announced a policy to accelerate the restart of existing nuclear power plants. He also indicated a policy of extending the operational life up to 60 years, and even considering the construction (replacement) of a new reactor. These nuclear policies represent the significant change in Japan since Russia's invasion of Ukraine.

The decarbonization strategy responding to Russia's invasion of Ukraine was published in December 2022, "Basic Strategy for Realizing Green Transformation (GX)"

a. Foremost effort for energy efficiency improvement
b. Making the renewable energies as a mainstream of power supply
c. Utilize nuclear energy
d. Other key areas

- Promote hydrogen and ammonia
- Reform gas and power market
- Strengthen resource diplomacy
- Battery industry
- Resource cycling
- Green transformation of the transport sector
- Digital investment
- Housing and building
- Social infrastructure
- Carbon recycling/CCS
- Food, agriculture, fishery, and forestry

3 Germany: Accelerated Replacement of Fossil Fuels While Diversifying Their Supply

In January 2022, shortly before the Russian invasion into the Ukraine (24.2.2022), the German Federal Ministry for Economic Affairs and Climate Action (BMWK, 2022) published "Germany`s Current Climate Action Status". According to this publication, the goals of the current government can be summarized as follows:

1 | Germany should be greenhouse gas-neutral in less than 25 years – in 2045 at the latest.
2 | Electricity supply in 2030 should be based on 80% renewables.
3 | Emissions reductions must more than double in the coming years and then nearly triple by 2030
4 | The Climate Change Act, following the Federal Constitutional Court's landmark ruling on climate protection in March 2021, requires that greenhouse gas emissions must fall by 65 % from 1990 by 2030. All sectors must contribute to this reduction by binding targets
5 | The European Union has set itself the goal of greenhouse gas neutrality by 2050 and has raised the 2030 target to a 55 per cent reduction in greenhouse gas emissions from the 1990 figure. Both targets have been made binding under international law by the European Union in the context of the Paris Agreement.

In this paper we take this political action status as a starting point to discuss the question whether and how Germany might have changed its basic strategies due to the impact of the energy crisis.

3.1 Medium Term Compensation for the Ban on Russian Fossil Fuels

Russia's war of aggression against the Ukraine has been perceived by the German Government and the public as a fundamental turning point ("Zeitenwende")[9] of geopolitics and as a dramatic break with rule-based foreign policies. This turning point came also as a challenge and surprise for many experts concerning current energy policies, import strategies, and long-term decarbonization strategies. The German Government decided on huge immediate relief programs for households and companies, which are not part of this paper.[10] Here we focus on the policies and measures to compensate for the ban on Russian gas, oil and coal (based, i.e., on Ariadne, 2022). There is no comparable industrialized country, where the historical, self-responsible and risky decisions on import dependencies (especially for gas) were as seriously challenging as for Germany. However, as a member state of the EU, Germany can rely on other member states to find solutions. The key question for the German Government, which was raised by the ban, was *whether, and if yes, how ambitious climate mitigation policies can be combined with protecting energy sovereignty and security of supply.* Following the events of February 2022, the Ministry of Economics and Climate Action (BMWK) is prioritizing the reduction and substitution of fossil fuels over their decarbonization. Highest priority is given to the question how much, how quick and with what socioeconomic implications the forced "reduction of fossil fuels" (e.g. by energy efficiency, renewable energies, diversification of supply) is possible, getting rid of the import dependencies.

9 Cf. e.g. Bundesregierung (2022): Reden zur Zeitenwende (bundesregierung.de)
10 Cf. e.g. Bundesregierung (2022): Wir entlasten Deutschland | Bundesregierung

Japan and Germany have taken different approaches to the energy crisis, with Japan focusing on decarbonizing fossil fuels and Germany prioritizing the reduction and substitution of fossil fuels.

This paper does not look into the specific challenges of "decarbonization of energy intensive industries"[11], where the wording "decarbonization of fossil fuels" can have a special meaning without referring to the energy crisis. Transforming the production processes in industries like steelmaking, aluminum, cement and chemicals (fertilizers), "decarbonization" includes a wide range of time horizons and technologies such as e.g., hydrogen, CCS, CCUS, low carbon products and CE strategies.

In Germany, there are many activities going on in research and the "scenario community"[12] e.g., to adapt the former scenario analyses to possible new challenges due to the changed international energy agenda after February 2022. Thus, the BMWK is moderating a scenario based dialogue on a "System Development Strategy" ("Systementwicklungsstrategie/SES"):

> "Against this background, there is a great need for coordination between the planning processes for infrastructure and the strategies for the various sectors and energy sources. The SES sets a framework that provides orientation for follow-up processes, such as the network development plans for electricity and gas or hydrogen, as well as the sector- and energy-source-specific strategies and programs. In this way, it ensures the coherence of the various strategies and programs in terms of an inexpensive, consumer-friendly, efficient, environmentally friendly and climate-neutral overall system. The SES is created by the BMWK in a participatory process involving representatives from the energy sector, industry, civil society and politics." (ibid; own translation)

We will come back to some of these initiatives at the end of this paper.

Figure 3-1 shows Germany's import dependency on oil, natural gas, and hard coal before the war, as well as the share that was imported from Russia.

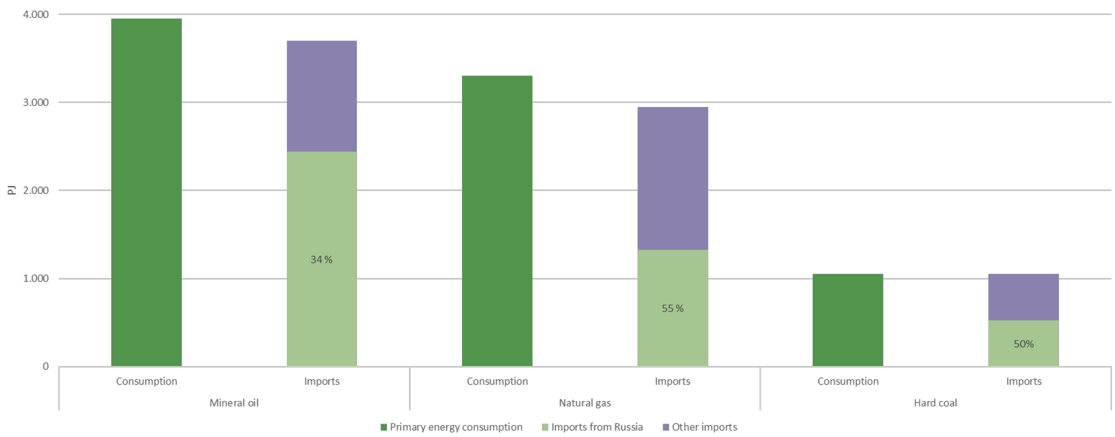

Figure 3-1 Fossil Fuel Import Dependency of Germany Before 2/2022

(Source: Ariadne 2022)

11 The GJETC conducted special papers on steelmaking and chemicals, see https://gjetc.org/studies/

12 https://www.bmwk.de/Redaktion/DE/Dossier/ses.html

Figure 3-2 illustrates the distribution of natural gas demand across key sectors up to 2020, including private households, the commercial sector, electricity and heat production, industry, and other sectors.

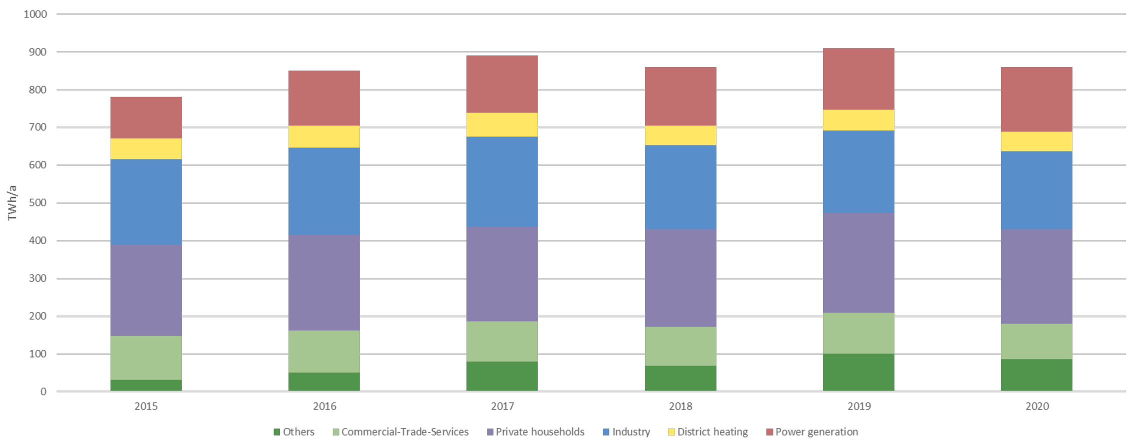

Figure 3-2 Sectoral Demand for Natural Gas in Germany

(Source: Ariadne 2022)

3.2 Stronger Energy Efficiency and Savings

Regarding natural gas conservation potential, Figure 3-3 displays the potential for mobilizing short-term energy conservation in various sectors, as indicated by different studies:

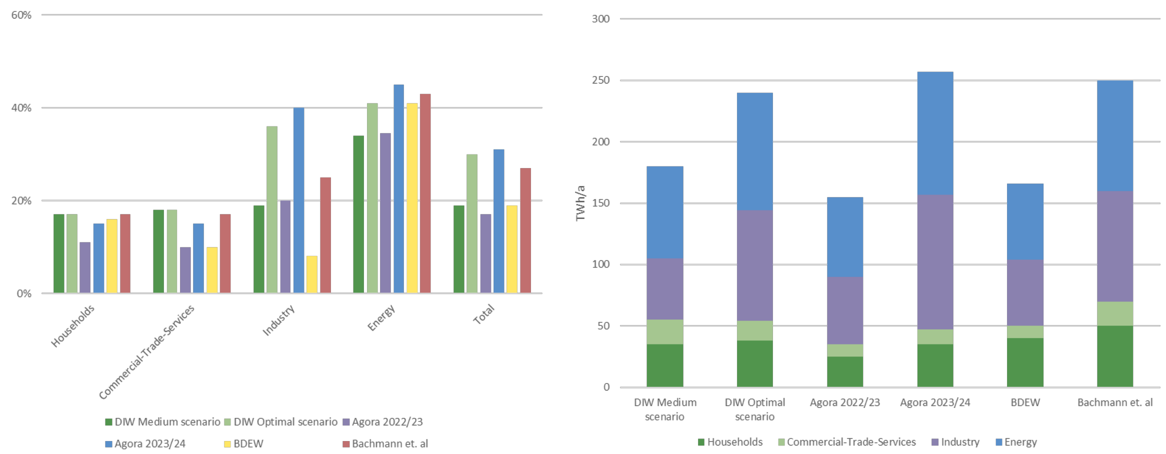

Figure 3-3 Short Run (2022/2023) Gas Conservation Potential According to Different Studies (left in % and right in absolute figures)

(Source: Ariadne 2022)

So, what has been accomplished in the short run? Several studies, including those by Agora (2022), UBA (2023) and BMWK (2022), summarize some key impacts as of the end of 2022:

- Emergency measures to ensure security of supply have generally been successful (BMWK, 2022), despite the cessation of all fossil fuel imports from Russia. During the winter period, gas consumption in Germany was reduced by around 19% compared to the period 2018-21 exceeding the 15% target set by the European Council (i.e., the governments of the EU Member States). However, the German energy grid regulator (Bundesnetzagentur) suggests that gas savings should have been even higher (25%) to characterize the status quo as “stable”.
- CO_2 emissions in 2022 decreased by 1,9%, which translates to 15 Mt less than in 2021. This reduction was mainly due to decreases in the industry and household sectors, while emissions in the energy and the transportation sectors increased.
- Primary energy consumption declined by 4.7% in 2022 compared to 2021, thanks to energy efficiency, energy savings, production declines, and low heating consumption due to mild weather. Fossil gas consumption fell compared to 2021, while oil and coal consumption increased by three and five percent, respectively.
- Renewable energy sources produced more electricity in 2022 than ever before, generating 256 TWh, a 9% increase compared to 2021. Wind power remains the largest supplier of renewable electricity with 128 TWh, but the addition of 2.4 GW was still far too low. Solar power production increased by 23% compared to 2021 due to a good year for sunshine and the addition of 7.2 GW.
- Two more coal-fired power plants, activated from reserve (2 GW), were on the market than at the end of 2021. As a result, lignite and hard coal-fired power plants supplied 18 TWh more, while generation from gas-fired power plants fell by 15 TWh.
- Surveys conducted among citizens on the most significant topics in Germany reflect the multiple crises of 2022. Climate and environmental protection were among the top two issues in the monthly polls during the year. A large part of the population sees the expansion of renewable energies as the best response to the Russian invasion. The acceptance of renewable energies is increasing again at a high level.
- Energy savings, increased gas imports, and the first three FSRU LNG terminals in German ports have brought gas prices down again (see below).

Figure 3-4 illustrates how the energy crisis initially caused a severe energy price crisis, which brought some companies and vulnerable households close to the brink of existence. Meanwhile, the gas price has nearly returned to its pre-war level, and Ariadne (2022) does not anticipate a similar future price hike as in 2022.

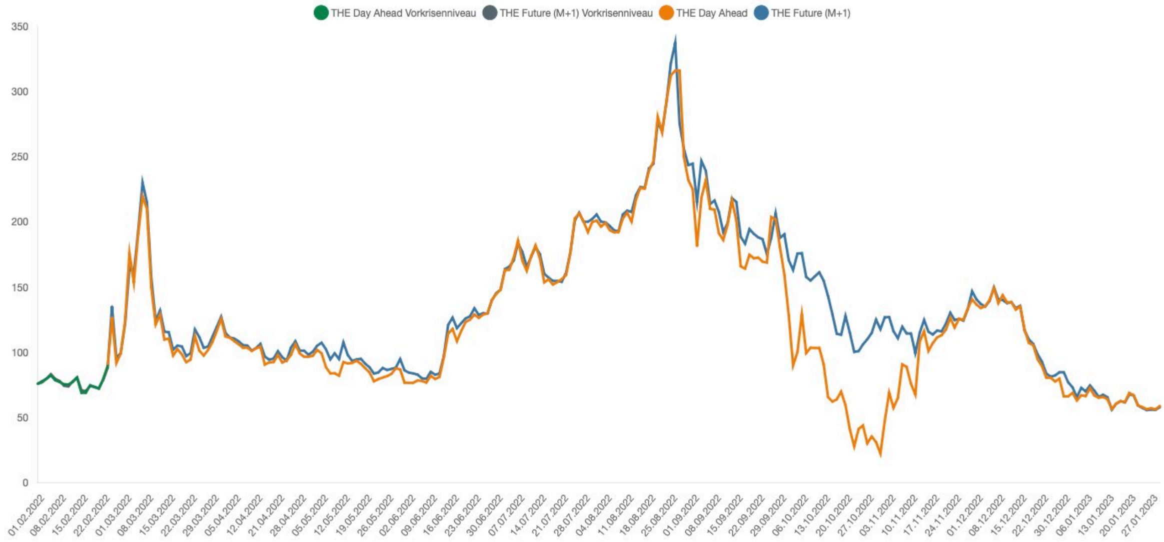

Figure 3-4 Wholesale Gas Prices 2/2022 to 1/2023

(Source: Bundesnetzagentur 2023)

What are the mid- and long-term prospects? As of February 2023, there are no fully adapted and updated scenarios compared to the representative studies, which have been compared by the GJETC (2022). Therefore, we refer to recent studies that focus on the gas market and renewable electricity prospects up to 2035.

Figure 3-5 summarizes the final result of the Ariadne study (2022). It shows how a mixture of energy efficiency and conservation measures in all sectors and additional LNG imports can substitute for the energy supply gap caused by the cessation of gas imports from Russia in 2022. Within its dossier, Ariadne (2022) examined the mid-term perspectives (up to 2030) of the gas supply and demand. It concluded that with support from additional LNG imports, about 600 TWh of gas supply from saved sources can be secured for Germany. This would mean a reduction of about 30 to 50% compared to the pre-war level of gas demand, which would also contribute significantly to achieving Germany's climate mitigation targets. However, it raises questions about how this energy efficiency and conservation effort can be reached and stabilized and what this would mean for the need to build up a comprehensive new LNG-infrastructure (see below).

For example, another study by E3G, together with the Wuppertal Institute, showed that a comprehensive program of energy efficiency, paired with green electrification and district heat in the building sector, could save up to 250 TWh/yr of gas by 2030 and avoid the need to build two land-based LNG terminals that are planned for 2026 and 2028 to replace FSRUs (Koch et al. 2022).

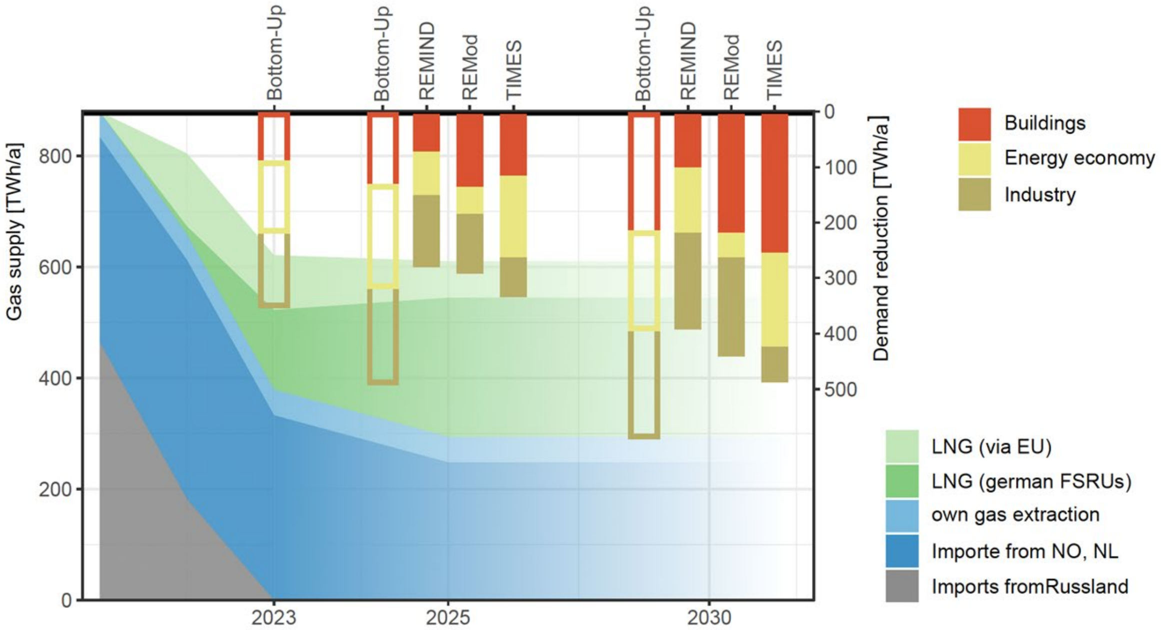

Figure 3-5 Sectoral and overall gas savings in a scenario energy sovereignty compared with the supply gap after the export stop of Russian gas

(Source: Ariadne 2022; estimated by bottom up and complete system analysis)

In sum, the Ariadne study identified energy savings potentials in the building, energy industry, and industry sectors to be "[…] in principle sufficient to reduce the gas consumption up to the year 2025 to a level, which enables a high level of energy sovereignty and especially independence of Russian gas imports. For this, a clear trend change in the energy industry and in buildings is necessary, which could not realize demand reductions up to now" (Ariadne 2022, 3, own translation).

The deficits of the existing energy efficiency and savings governance have been perceived as one of the weakest points of the German climate mitigation and energy transition policies (BMWK 2022). Up to now, there is no binding target on energy efficiency, and it is unclear which institution bears the steering and coordination responsibilities for the implementation of cross-cutting saving policy packages to harvest the "low hanging fruits" of energy efficiency.

With this background and due to pressure from the EU, an Energy Efficiency Law ("Energieeffizienzgesetz"/EEG) with mandatory targets and a comprehensive revision of the Buildings Energy Law ("Gebäudeenergie-Gesetz"/GEG) are under development, which might bring some progress in the near term. The government has implemented further plans with detailed measures (see below).

The Ariadne Study noted that the *extension of the life of the three remaining nuclear power plants up to April 20*23 "[leads] to additional electricity exports and reduces the GHG-emissions, but contributes only marginally to gas savings in Germany" (Ariadne 2022, 2).

Although the Ariadne Study focuses on the gas supply topic and does not discuss the implications of an ambitious reduction of the gas demand (30 to 50% by 2030) for the existing gas infrastructure, the profitability of the gas grid, and the transition to a hydrogen economy, there is growing concern about the future of the gas grid within the community of many Municipal utilities in Germany (about

850). Municipal utilities are worried about whether gas grids "remain a business case" (ZfK 2023, February, 2). In the future, it appears clear that the fixed cost of the grid must be distributed to less gas supply, which would mean raising transmission fees. The question of blending natural gas with hydrogen or developing a special hydrogen grid is also being debated within municipal utilities (cf. ibid). Transformative planning has become an imperative for local and regional heat planning, and the task is accelerated by the energy/gas crisis.

3.3 Accelerated Deployment of Renewable Power

It is remarkable how the German government reacted to the energy supply and price crisis after 2/2022 by deciding on a very comprehensive package of measures to speed up the market introduction of PV and wind. This move also implemented the government's plans from the coalition treaty of November 2021.

The German government has decided on dozens of specific measures especially to speed up the implementation of wind power (offshore/onshore) and of PV. Among others, the following key decisions are expected to help to boost the market deployment (BMWK 2023):

- The newly introduced principle that "RE is in the overriding public interest and serves public safety". This means that renewables will have priority over other interests when making weighing decisions. It is expected to increase the speed of planning and approval processes.
- In the case of PV-roof systems with fixed remuneration, the remuneration will be increased from up to 6.24 cents/kWh to up to 13.4 cents/kWh.
- Introduction of the 2% area target for all federal states: states are obliged to make sufficient areas available for the expansion of wind energy on land.
- Wind and solar projects from citizen energy companies up to a size of 18 MW (wind) and 6 MW (PV FF) no longer have to participate in tenders from 2023.
- The expansion targets for offshore wind energy have been significantly increased to at least 30 GW by 2030, at least 40 GW by 2035 and at least 70 GW by 2045 and are legally anchored in the WindSeeG.

Despite the progress made in the deployment of renewable power, there are still challenges to overcome. The integration of renewable power into the grid and the need for energy storage solutions are major issues that require attention. Additionally, the future of coal-fired power plants needs to be addressed, as the government has set a goal to phase out coal by 2038 at the latest. This will require a significant increase in renewable power deployment and energy efficiency measures.

The technical feasibility of transforming the power sector to 80% renewables by 2030 and achieving a completely carbon-neutral electricity system by 2035 has been analyzed in a recent study by Agora Energiewende (2022), which was published in June 2022. The study evaluates the specific challenges associated with this transition, in accordance with the coalition treaty and the EEG 2023, and builds on the recent carbon-neutral scenarios for 2045.

While the study could not address the specific additional challenges posed by the ban on fossil fuel imports from Russia, it is certain that the German government remains committed to the expansion plans for wind and PV, and considers energy sovereignty as a key factor in decarbonizing the economy.

The expansion of wind and solar PV must be given a much higher priority, combined with a paradigm shift in the development of power and hydrogen grids, and flexibility resources, if renewable energy is to cover 80% of electricity consumption in Germany by 2030. Faster planning and approval procedures must also be established to facilitate this transition.

The phase-out of coal and the establishment of a climate-neutral power system by 2035 will depend on the combination of 80% renewable electricity and gas-fired power plants that increasingly run on renewable hydrogen. One of the biggest challenges to achieving a switch to green electricity in industry, buildings, and transport is the need for a coordinated strategy for electrolyzers, electric vehicles, heat pumps, and, in some cases, electrode boilers, which must be implemented from the outset. Additionally, this strategy must be supported by a reform of grid charges, the intelligent operation of distribution grids, and a comprehensive smart meter rollout. Figure 3-6 illustrates how the demand for green electricity is expected to accelerate due to the electrification of the transport sector (through battery electric vehicles wherever feasible) and the building sector, by promoting the market introduction of heat pumps.

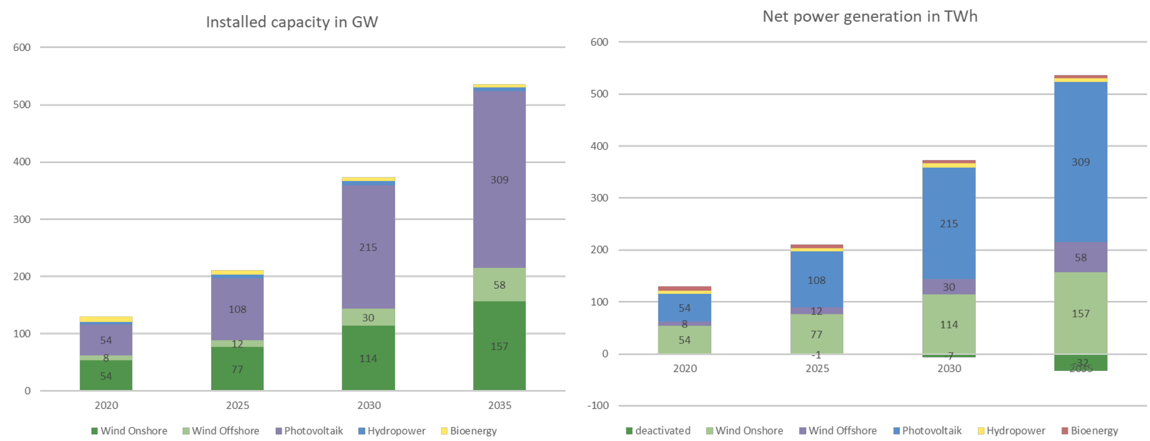

Figure 3-6 Installed capacity and net electricity production from renewable energy sources in the Agora-Study

(Source: Agora 2022)

Figure 3-7 illustrates compared to the past the unprecedented speed required for the yearly capacity increase of PV and wind up to 2035. Therefore, the question arises as to what extent this *rapid increase* could be facilitated by a targeted Energy/Electricity Savings Strategy and by initiating a supporting sufficiency policy to anticipate and, if possible, avoid rebound effects.

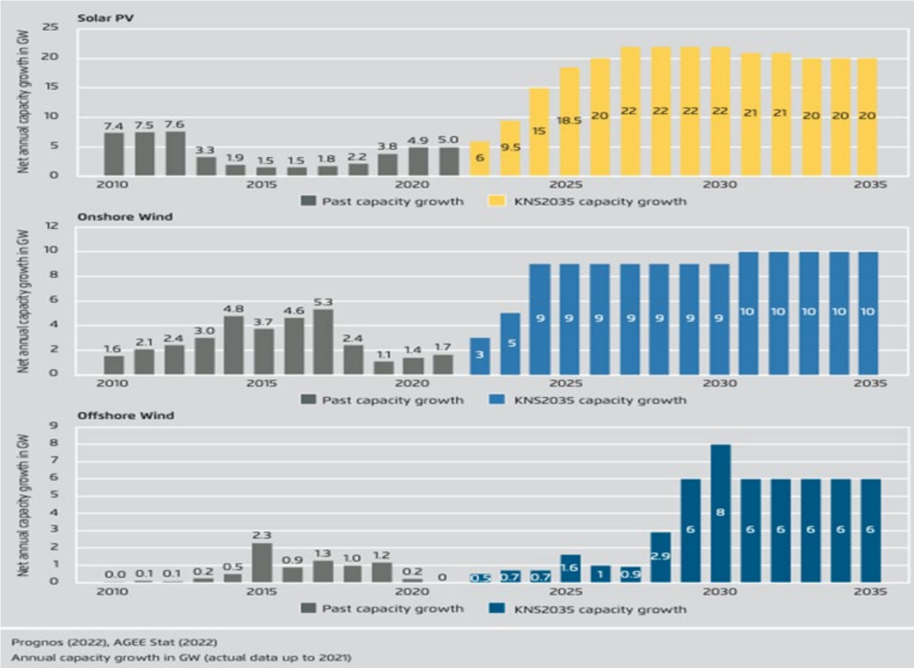

Figure 3-7 The necessary speeding up of capacity increase for wind and PV to meet EEG 2023 targets according to results of the Agora 2022 study

It is noteworthy that the Expert Council on Climate (2022) has identified electricity conservation as a special recommendation to the government (see below), but there is no public information available yet on whether the government is acting on these recommendations.

The Agora study found no fundamental objections to a high share of fluctuating PV and wind supply (see Figure 3-8) if dispatchable generation is used in combination with flexibility resources such as electricity and heat storage and demand-side management.

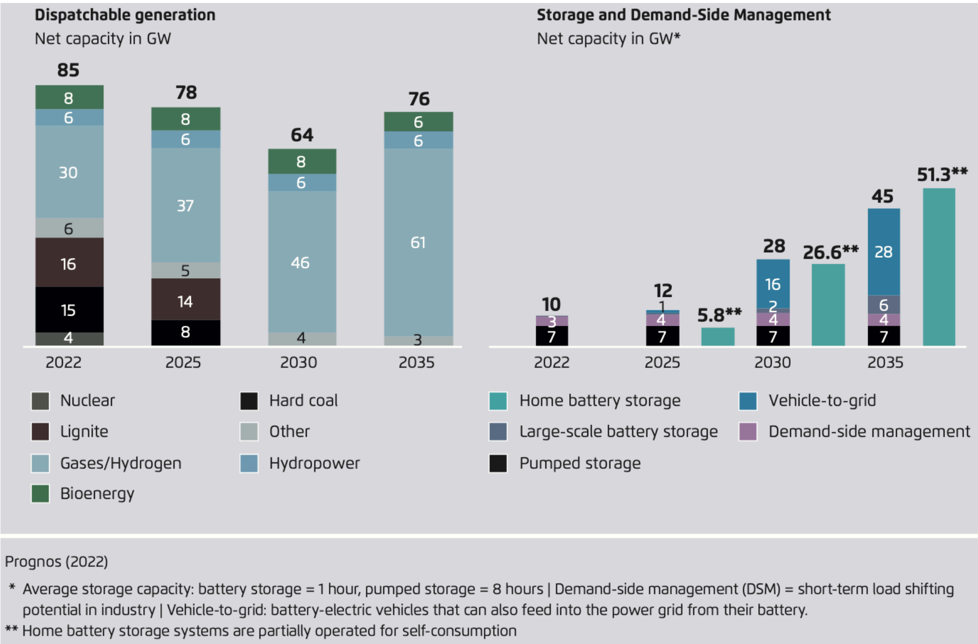

Figure 3-8 Dispatchable generation, Storage and Demand-Side Management

(Source: Agora 2022)

As previously mentioned, the Agora study was conducted and published before the ban on Russian gas imports. Nevertheless, it is interesting to note how the study perceives the usage and conservation of gas. Agora confirms the energy conservation analyses of the Ariadne Study, demonstrating that it is feasible to reduce gas demand from 861 TWh to about 620 TWh by 2030 through energy efficiency alone. All sectors must contribute to these energy savings, but a key question remains unanswered: how can the existing energy efficiency potentials be realized in practice? Past monitoring studies have criticized the existing energy efficiency policy package for being insufficient to fully realize all cost-effective potentials. In addition, Agora highlights the important role of controllable gas power plants if they are constructed from the start to be “H2-ready”:

> *“In 2035, 89 percent of renewable electricity is directly generated by renewables and 7 percent is generated in hydrogen power plants…. To back-up this dependence on variable renewables, dispatchable gas-fired power plants are used in the 2030s to cover the residual load. Generation from these plants trends downward, from 107 TWh in 2030 to 86 TWh in 2035. In the climate-neutral electricity system of 2035, the installed capacity of gas-fired power plants doubles from 30 GW (2022) to 61 GW. Fossil gas is increasingly replaced by hydrogen, so that the share of fossil gas in electricity generation is only two percent in 2035. In 2030, electricity generation from hydrogen amounts to about 13 TWh. This will require 4 to 6 GW of hydrogen-capable power plants. In 2035, gas-fired power plants will generate 86 TWh of electricity. ..For the successful implementation of the energy transition, three ramp-up paths in the hydrogen sector are crucial and must be initiated immediately: hydrogen production; hydrogen-capable power plants; and hydrogen infrastructure. Starting now, new power plants must be 100 percent H_2-ready. To ensure that the production and consumption of the rapidly increasing amounts of hydrogen can be coordinated in terms of location and time, new hydrogen transport and storage infrastructure will be necessary. The options of using the hydrogen derivative ammonia in power plants must also be examined in order to counter shortages in hydrogen supply, as ammonia is particularly easy to import.”* (Agora 2022, p.7) [13]

In conclusion, the decarbonization of the German energy sector is a complex and multifaceted challenge that requires ambitious and coordinated efforts across all sectors. The initiatives outlined in this chapter represent important steps towards achieving Germany's climate goals, but further action and transformative planning will be necessary to ensure a successful energy transition. In the next section, we will examine sector-specific initiatives that aim to decarbonize other industries beyond the power sector, such as transportation and buildings. These sectors are essential for achieving the climate targets set by the German government, and there are already a variety of efforts underway to reduce their carbon footprint.

3.4 Other Sector-Specific Decarbonization Initiatives

In the context of the Expert Council on Climate's Biennial Appraisal in November 2022, it was noted that current emission reduction rates are insufficient to achieve climate protection goals by 2030 (ERK 2022). The Council recommends addressing changes in consumer behavior and rapid restructuring of capital stock to meet climate goals. This chapter highlights that sufficiency policies could be a valid and effective third pillar in combination with efficiency and renewables in decarbonization strategies. The aim of sufficiency policies is to enable and empower people to

[13] https://static.agora energiewende.de/fileadmin/Projekte/2021/2021_11_DE_KNStrom2035/AEW_KNStrom2035_Summary_EN.pdf

change their daily routines and practices towards more sufficient choices through adequate public and non-motorized transport infrastructures, energy-saving building technologies, and appliances. Sufficiency policies should be perceived as contributing to a better quality of life, especially for vulnerable households who suffer most from climate change but cause much less emissions (Chancel, L. 2022). The IPCC's special report on Global Warming of 1.5˚C includes an interesting observation on the significant role of behavior change and demand-side management in reducing emissions:

> *"**Political and financial stakeholders may find climate actions more cost- effective** and socially acceptable if multiple factors affecting behavior are considered, including aligning these actions with people's core values […]. Behavior- and lifestyle- related measures and demand-side management have already led to emission reductions around the world and can enable significant future reductions […]. Social innovation through bottom-up initiatives can result in greater participation in the governance of systems transitions and increase support for technologies, practices and policies that are part of the global response to limit warming to 1.5°C."* (IPCC 2018, 317).

Finally, the German Climate Protection Act has defined binding sectoral CO_2 reduction targets up to 2030, and it is crucial to create and implement action plans to meet these targets[14].

3.4.1 The Transport Sector

The challenge of meeting emission targets in the car-oriented German mobility system has led to unresolved fundamental controversies about suitable countermeasures within the current Coalition of the SPD, Grüne and FDP parties. Traditionally, the German Ministry of Transportation is led by ministers from political parties that prioritize private car mobility, which is also true for the current FDP minister who advocates for the expansion of Autobahnen as a new planning priority, arguing that it lies in the overriding public interest. This planning principle would give the green light to an expansion plan for new and larger Autobahnen according to the current Federal Transport Route Plan ("Bundesverkehrswegeplan"). This "car mobility first" concept is fiercely opposed as outdated by the Green Party, NGOs, most transportation experts, and is not compatible with the binding targets of the Climate Law. "Germany does not need more motorways, trunk roads or airports per se [...]. This is in contradiction to the desired climate neutrality"[15].

This dispute is not yet resolved (as of February 2023), and it presents an opportunity for Germany to learn from Japan, especially when it comes to public transportation and a rapid train system like the Shinkansen. However, transforming the transportation system to a decarbonized and more equitable system of "Sustainable Mobility for all" (Hennicke et al., 2021) is a highly complex undertaking in Germany.

Therefore, this topical paper will not expand further on the topic of transportation. With the background of this paper analyzing the impact of the energy crisis, this seems justified for Germany, as the energy price and supply crisis only partly affected the transport sector. From April 2022 (all-time high 2,27 €/l), to October 2022 (1,78€/l) and January 2023 (2,03 €/l), the German gasoline

14 Cf. https://www.bundesregierung.de/breg-de/themen/klimaschutz/climate-change-act-2021-1913970

15 Own translation of Dirk Messners quote in Bauchmüller, M. 2022: https://www.sueddeutsche.de/politik/verkehrswende-strassenbau-verkehrsministerium-1.5723704

price fluctuated, and the state offered a fuel discount, moderating the impact of the energy price crisis.

However, it should be noted that decarbonizing the automobile sector in Germany is entirely guided by the concept of e-mobility wherever possible. Thus, the additional green electricity needed to decarbonize the transportation sector depends on the future role that individual automobility should and can play, as there are many interlinkages within the context of sector coupling. In general, two contradictory approaches are competing: Some people expect that the number of cars (48.5 million in 2022), the average weight (trend to SUVs), and the increasing average horsepower (for new cars between 200-250 in 2022)[16] can grow if the fleet is powered with green electricity. The German Environment Agency argues that by enabling more sustainable transportation modes (e.g., public transportation, bicycle, sharing), the fleet can be halved and must be downsized to be in line with climate mitigation and resource protection targets. There are strong arguments, not only concerning climate mitigation, but also concerning area conflicts, protecting the countryside, and raising the quality of life in cities, that the guiding principle of "Sustainable Mobility for all" could gain more public acceptance then an "all electric car" strategy (Hennicke et al., 2021).

Overall, the transport sector in Germany faces complex challenges in its transformation to sustainable mobility, and finding suitable solutions will require cooperation and innovation from various stakeholders.

3.4.2 The Building Sector

According to the monitoring report on the development of CO_2 emissions in the building sector, "[F]inal energy consumption in the building sector increased by 4.2 percent in 2019 compared to the previous year. It has fallen by an average of 1 percent per year since 2008. The savings target for 2020 (minus 20 percent) will therefore not be achieved" (BMWi 2021, 7). This gap has not yet been closed in 2021, but the "Expertenrat für Klimafragen" is more optimistic about a possible switch to the CO_2-target reduction plan in the building sector. An emergency program became necessary because the emissions from the building sector in 2021 exceeded the permitted annual emissions by two million tons of CO_2 equivalents (115 Mt CO_2 eq. instead of 113 Mt CO_2 eq.).

Figures 3-9 and 3-10 demonstrate what it would mean to bring the building sector in line with a decarbonization strategy up to 2045. Both figures were selected from Prognos/Öko-Institut/Wuppertal Institut 2021, which modelled a comprehensive decarbonization strategy by 2045. The message is straightforward and has not changed since the energy crisis: gas and oil have to be substituted by 2040 at the latest through energy efficiency, reducing the heat demand, and supplying a growing share of heat pumps with green electricity and green district heat. Although policies and measures addressing the rapid transformation of the heat market as a response to the energy supply and energy price crisis are not yet as comprehensive as in the energy sector, important steps have been decided that might speed up the transformation process.

[16] Cf. https://www.autolist.com/guides/average-car-horsepower

Figure 3-9 The building sector: Final energy demand and supply for heat in a 2045 net zero scenario

(Source: Prognos/Öko-Institut/Wuppertal Institut 2021)

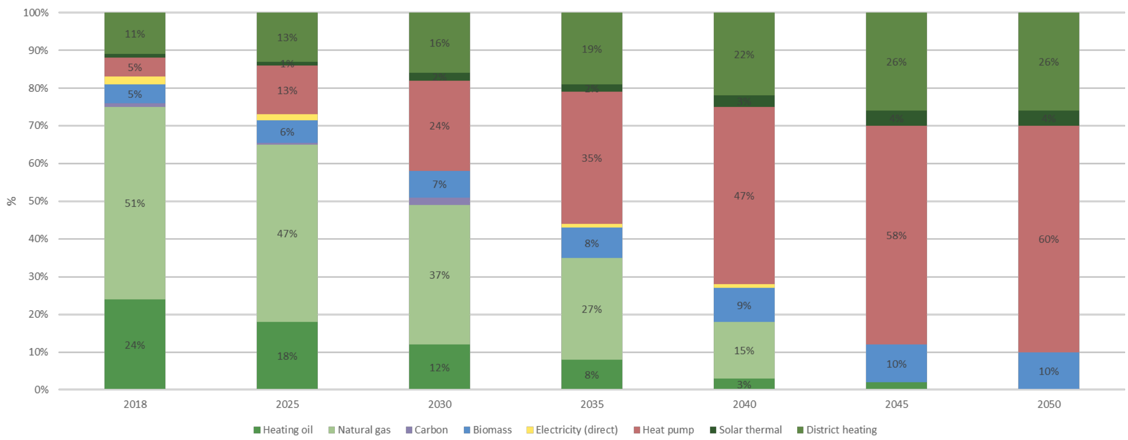

Figure 3-10 Heating structure of the living space

(Source: Prognos/Öko-Institut/Wuppertal Institut 2021)

Below are some key measures that the government has decided to speed up the energy transition in the heat sector. It is apparent that these are important announcements to reduce CO_2 emissions in the heat sector. But compared to the power sector, there is neither a comparable ambitious target setting up to now, nor a clear Action Plan on how these measures can work together to get the building sector back on the CO_2-reduction path[17]:

1 | 1st amendment of the Building Energy Act (GEG)

Among other things, the GEG amendment is intended to stipulate by law that from January 1, 2024, every newly installed heating system should be operated with 65% renewable energy if possible. According to the coalition agreement, the new building standard is to be adjusted to the EH40 standard from 2025[18].

17 cf. GJETC Building Study 2023

18 Cf. BMWSB and BMWK 2022: https://www.bmwsb.bund.de/SharedDocs/pressemitteilungen/Webs/BMWSB/DE/2022/07/sofortprogramm-klimaschutz-gebaeude.html

2 | **Federal Funding for Efficient Buildings (BEG)**
The guiding principle for the realignment of the BEG is to ensure that the building stock will be climate-neutral by 2045. The current renovation dynamics should be maintained. The government plans to spend 12 to 14 billion Euros per year on financial support for building energy renovation and green heating systems until 2026.

3 | **Guideline for the Funding of Pilot Projects for Serial Refurbishment and Accompanying Measures**
Serial renovation is an innovative method for building renovation that has been funded since May 7, 2021 : With prefabricated roof and facade elements, including the associated system technology, buildings are to be renovated quickly and with high quality in terms of energy efficiency.

4 | **Initiative Public Buildings**
A new measure to increase the refurbishment rate for all public buildings is intended to achieve a higher ambition level of

5 | **Redevelopment of Municipal Facilities in the Areas of Sport, Youth and Culture**
With a federal program "Renovation of municipal facilities in the areas of sport, youth and culture", municipal facilities in the areas of sport, youth and culture are to be promoted with high quality in terms of their energetic effects and adaptation to climate change.

6 | **Zukunft Bau - Model Project for Innovation in the Building Sector**
The Zukunft Bau funding program supports model projects that test promising research and development solutions in practice.

7 | **Federal Funding for Efficient Heating Networks (BEW)**
The BEW provides incentives for the conversion of predominantly fossil heating networks to renewable energies and waste heat, as well as the construction of new heating networks with at least 75% feed-in from renewable heat and waste heat.

8 | **Municipal Heat Planning Act**
A federal regulation is planned to introduce municipal heating planning (KWP) in a timely and effective manner with a view to climate targets. The exact design of the federal regulation on the KWP is currently still open.

9 | **Heat Pump Development Program and Qualification Offensive**
Heat pumps are a key technology in the heating sector due to their high degree of efficiency and potential greenhouse gas neutrality. However, there is a widespread shortage of skilled workers, which must be countered with a comprehensive training concept.

10 | **Optimization of Existing Heating Systems**
Various regulatory implementation options beyond funding are currently being developed and discussed. The aim is to promptly initiate an optimization of existing heating systems.

11 | **Energy Efficiency Act (EnEfG)**
The Energy Efficiency Act creates a cross-sectoral legal framework for increasing energy efficiency is created for the first time, laying down the ambition level of the Climate Protection Act for energy efficiency.

Despite these efforts, conflicting developments have occurred, as demonstrated by the fact that in 2022, while the heat pump market grew strongly with just under 230,000 heat pumps sold, an estimated 600,000 gas boilers and 50,000 oil boilers were also sold. With normal lifetimes of 20 to 30 years, many of these boilers would still be in operation in 2045. To address this issue, the government, the heating system industry, and the installation business have recently agreed to work together to achieve 500,000 heat pump installations in 2025. Further increasing numbers will be needed in the years thereafter to achieve the target of 6 million heat pumps in 2030.

In summary, the building sector's decarbonization is a highly complex undertaking that requires comprehensive efforts and cooperation between different stakeholders. The government has taken several measures and enacted policies to speed up the energy transition in space and water heating, such as the 1st amendment of the Building Energy Act, federal funding for efficient buildings, funding for pilot projects for serial refurbishment, and municipal heat planning act. However, more ambitious targets and a clear action plan are still needed to bring the building sector in line with a decarbonization strategy up to 2045.

3.5 How Much Additional LNG Terminals and Capacity is Needed?

Until February 2022, various climate protection scenarios assessed how to achieve the 2045 decarbonization target in Germany. However, the global energy and supply crisis triggered by the Russian aggression against Ukraine presented a new challenge to the continuity of the previous scenarios. These scenarios included natural gas as a "bridge" to decarbonization, along with the expansion of renewable energies and increased energy efficiency. To safeguard national energy sovereignty and supply security the German government temporarily put 2 GW coal-fired power plants back into operation, extended the service life of the last three nuclear power plants, and purchased expensive natural gas to fill gas storage for the winter of 2022/23.

However, the government's most important short-term supply-side decision was to compensate for the loss of Russian pipeline gas volumes by stepping up entry into the international LNG market and building its own LNG terminals. As of December 2022, 11 import terminals are planned in Germany, 7-8 of them being floating FSRU terminals and three large terminals on land. The FRSU terminals are expected to be operational by the end of 2023, while the land terminals are expected to be launched in 2025-2027. The following list provides an overview of the planned LNG terminals' locations and capacities.

Table 3-1 Overview on the planned LNG-Terminals in Germany, status dec. 2022

FSRU-Terminals (dez. 2022 – dez. 2023)		
Name	**Operator**	**Capacity**
FSRU Wilhelmshaven 1	Uniper	7 bcm
FSRU Wilhelmshaven 2	TES / Eon	5 bcm
FSRU Wilhelmshaven 3	NWO	unclear
FSRU Stade	Hanseatic Energy Hub	5 bcm
FSRU Brunsbuettel	RWE	5 bcm
FSRU Lubmin 1	German ReGas	5 bcm
FSRU Lubmin 2	German ReGas	7 bcm
FSRU Lubmin Investments	RWE / Stena Power	5 bcm
Land Terminals (2025-2027)		
Land terminal Wilhelmshaven	Tree Energy Soluctions (TES)	16-20 bcm
Land terminal Strade	Hanseatic Energy Hub	13 bcm
Land terminal Brunsbuettel	Gasunie	8 bcm

(Source: Energy Comment 2023)

The planned capacity of all the LNG terminals in Germany adds up to at least 73-76 bcm, which is significantly higher than the 46 bcm imported from Russia before the war. Prior to the war, around

97% of Germany's imported natural gas came from Russia, Norway and the Netherlands. However, the Netherlands has now become a net importer of natural gas.

There is an ongoing debate about the quality of the supply chain of natural gas to Germany. Methane emissions from the gas sector contribute significantly to climate change. Energy Comment (2023) recommends that German gas importers and their suppliers should reduce their methane emissions by using certified suppliers and transparent documentation of their supply chains. According to Energy Comment, Norway has the most sustainable supply chain to Germany, followed by certified gas from the USA and then Qatar.

There are four key questions surrounding Germany's decision to import LNG: 1) How will the international LNG markets and geopolitical supply conditions be impacted by the energy crisis? 2) Where will the additional LNG imports come from, and what is the climate impact of these supplies? 3) Could new LNG terminals become stranded assets? 4) What are the technical and economic considerations for converting LNG terminals to use liquid hydrogen or green ammonia?

The USA is expected to supply a large share of European and German LNG imports. Figure 3-11 demonstrate that natural gas from the USA is likely to substitute for Russian imports under both low and high gas demand projections.

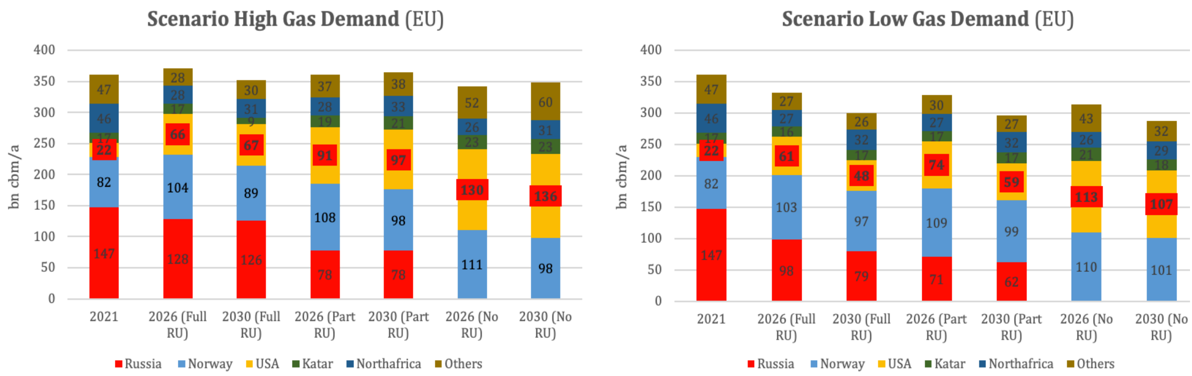

Figure 3-11 Gas import scenarios of the EU: Predicting the USA as major supplier by 2030

(Source: EWI 2022)

A recent study of the New Climate Institute (2022) questions the necessity of planned LNG terminals in Germany, as gas consumption will need to be further reduced to achieve climate neutrality. The study suggests that if all gas savings potentials were used, a floating storage and regasification unit (FSRU) capacity of around 30 billion cubic meters would be sufficient in 2025 (cf. Figure 3-5 of Ariadne 2022). The risk of stranded assets and fossil fuel lock-ins from overcapacity of LNG terminals could be reduced by planning for conversion to climate-neutral energy carriers from the beginning.

In summary, the integrated decision of the German government to combine ambitious climate mitigation with security of supply raises important questions regarding the quality of LNG supplies, the risk of stranded assets, and the feasibility of terminal conversion to climate-neutral energy carriers.

3.6 New Industrial Policy Initiatives to Mitigate the Energy Crisis and Climate Change

Chapter 3.6 discusses the influence of international climate policy developments, particularly the Inflation Reduction Act (IRA) of the US, on European and German decarbonization strategies. While the IRA is estimated to reduce domestic GHG gas emissions, concerns have been raised in Europe over its "Buy American" features, which may contravene international trade rules and discriminate against foreign producers. This has led to calls for a strong European response, possibly including EU subsidies, which could create trade tensions and a subsidy race. However, the IRA also signals a possible paradigm shift towards transformative supply policies and massive reduction of CO_2 emissions in the basic industry with state aid.

3.6.1 The Inflation Reduction Act and the EU

The decarbonization strategies of Germany and Europe are strongly influenced by international climate policy developments, particularly those from the United States, and most recently by the decision on the Inflation Reduction Act (IRA 2022).

While the IRA is welcomed for putting the United States on track to achieving its 2030 Nationally Determined Contributions (NDCs) and reducing domestic greenhouse gas (GHG) emissions by an estimated 40% by 2030 (from 2005 levels), there is growing concern in Europe regarding certain "local content requirements" (e.g., for electric vehicles and clean energy technologies) and subsidies that may contravene international trade rules and discriminate against foreign producers by favoring US companies (E3G 2022, 2ff).

It has been argued that the IRA's nationalist "Buy American" and trade-restricting features had to be accepted as an inevitable compromise due to the weak majority of the Democrats, complicated bargaining within the party, and necessary alliances with labor unions. Nonetheless, President Macron and Chancellor Scholz are calling for a strong European response, which could include the EU ramping up its subsidies. President Macron has repeatedly called for a ‘Buy European Act’, citing a possible EUR 8 billion loss in green investment due to the IRA (Ibid, 8).

The conflict may lead to a subsidy race between wealthy regions like the EU and US, creating a massive barrier against fair global competition with highly negative effects on countries of the Global South, which lack the resources to subsidize clean industries. The E3G study points out that these possible trade tensions between the US and EU underscore "the need for a green overhaul of rules in the international trade regime" (Ibid, 14). The G7 suggestion of a Climate Club[19] might be a suitable forum to settle these trade conflicts.

The impact of the IRA and accompanying bills in the US goes beyond trade and competition. It also signals a possible paradigm shift of economic policies. The Chips and Science Act[20], a new US legislation to expand the US semiconductor sector against Chinese dependence with $280 billion, was reported under the heading "Why industrial policy is back." In the EU, investment funding in the NextGeneration EU Recovery Plan and the conceptual ideas behind the European Green Deal

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[19] Cf. 2022-06-28-g7-climate-club-data.pdf (g7germany.de)
[20] Cf. FACT SHEET: CHIPS and Science Act Will Lower Costs, Create Jobs, Strengthen Supply Chains, and Counter China | The White House

are leading in a comparable direction. Recently, Minister Habeck used the term "Transformative supply policies." This means targeted and massive reduction of CO_2 emissions in sectors of the basic industry with state aid to enable investments in sustainable decarbonization technologies that are not yet profitable on the market.

3.6.2 The EU “Green Deal Industrial Plan”

On May 18th, 2022, the European Commission published its immediate response to reducing dependence on Russian fossil fuels through the REPowerEU plan (EUC 2022). This plan builds on the Fit for 55 package of proposals and completes actions on energy security of supply and storage. The plan proposes a set of actions that include saving energy, diversifying supplies, quickly substituting fossil fuels by accelerating Europe's clean energy transition, and smartly combining investments and reforms. A detailed list of activities can be found in the annex of the document. In this context, the activities can be summarized under a comparable heading like the German reaction: accelerated replacement of imported fossil fuels and diversifying the supply. For example, the energy efficiency target by 2030 was proposed to be increased by 4%, and the renewable target by 5%, both increases compared to Fit for 55.

On February 1st, 2023, the European Commission released its “Green Deal Industrial Plan”[21] “[…] to enhance the competitiveness of Europe's net-zero industry and support the fast transition to climate neutrality. The Plan aims to provide a more supportive environment for the scaling up of the EU's manufacturing capacity for the net-zero technologies and products required to meet Europe's ambitious climate targets.” (EUC 2023). This initiative is a response to the Inflation Reduction Plan (IRA) of the USA, but it is formulated politely. The Commission lists batteries, wind power plants, heat pumps, solar, electrolyzers, and CCS among the technologies that will be targeted. However, the precise product scope remains to be defined, taking technology neutrality as a starting point, and building on an assessment of strategic importance and identified needs of manufacturing investment in different types of net-zero products. Thus, many highly debated topics between EU member states are excluded up to now by this footnote. For example, Nuclear Europe immediately welcomed the "principle of technology neutrality" and pointed out the EU Sustainable Finance Taxonomy, which includes nuclear and natural gas up to now. Nine EU countries wrote a letter to the European Commission demanding technology neutrality, which, in this case, means equal incentives to be set for both renewable and low-carbon hydrogen, proposed to be produced by nuclear.

Some criticized the absence of a structural focus on energy efficiency as a significant risk to the overall success of the plan or the possible detrimental effects of national subsidies schemes on the cohesion of the EU. Specifically, France and Germany were mentioned, which might benefit from relaxed EU state rules on subsidies at the expense of poorer member states with limited resources to subsidize their industries. To enable these member states to support net-zero technology investments, the European Commission proposed a new European Sovereignty Fund as part of the Green Deal Industrial Plan.

[21] Cf. the detailed communication of the EUC: COM_2023_62_2_EN_ACT_A Green Deal Industrial Plan for the Net-Zero Age.pdf (europa.eu)

3.7 Summarizing the German/EU Crisis Response

The main developments and paradigm of the German/EU response to date can be summarized as follows:

- The basic medium-term strategy of Germany and the EU against the energy crisis is to accelerate climate mitigation actions such as energy efficiency, renewable electricity, electrification of end uses, and green hydrogen, both domestically and in supply chains for imports.
- The strategy aims to achieve strong synergies between energy security and climate mitigation.
- The German government expects power generation to be nearly 100% supplied by renewable energies in Germany by 2035.
- As a consequence of this strategy, natural gas demand may decrease by up to 50% by 2030, and coal phase-out may be accelerated ideally to 2030.
- However, there is no strategy yet for energy efficiency and sufficiency policies to maintain the level of energy savings achieved in the winter of 2022/23, such as with 20% of gas savings.
- Supply of natural gas, oil, and coal has started to diversify since the summer of 2022, replacing almost all imports from Russia by now.
- The LNG import infrastructure has been considerably expanded. However, the capacities planned for installation during the next five years are higher than the historic level of imports from Russia, which is not consistent with the strategy to reduce gas consumption, and may lead to significant import capacity reserves or stranded investments.
- The budget committee of the German Bundestag has requested the government to estimate future gas demand to avoid unnecessary costs to taxpayers.
- The EU and the German strategies against the energy crisis are focused on maximizing synergies between energy security and climate mitigation, but debates among member states about using nuclear energy or questioning the ambition level of decarbonization of the building stock and transportation sector are ongoing.
- In Germany, the debate on speed, necessary public financial support, transformative governance, and needed workforce for decarbonizing buildings and transportation is intensifying.
- Successful implementation processes towards net-zero require courageous target setting by governments, transparent decisions according to the guideline of a "just transition," positive narratives of the common transformation goals, and public participation at all political levels to explain the necessity of climate mitigation strategies and gain public support and the majority of voters.

In 2023, political debates and decisions will be crucial in setting the course for a pathway that achieves synergies between energy security and climate mitigation. The EU often plays a leading role in driving dialog and political processes on these synergies, but debates among Member States and within Germany continue.

4 Comparison of German-Japanese Crisis Management Paradigms

On the way to carbon neutral societies, Germany and Japan face common and differentiated challenges, such as:

- Both countries have low energy self-sufficiency rates, and the path to a carbon-neutral society should prioritize exploiting national potentials for energy and resource efficiency, and renewables to strengthen national energy sovereignty.
- Germany, connected to its neighbors by land, can import and exchange a wide variety of energy, while Japan has to rely on commodity imports by ship which gives less flexibility in term of transaction amount and no power trade is possible with neighborhood countries.
- Both countries are confronted with future challenges of rising shares of imported hydrogen and derived synfuels, the need to diversify H2-suppliers, and to decarbonize hydrogen as quickly as possible.
- There are also differences between the two countries in terms of their current policies for achieving carbon neutrality. Germany focuses on the reduction of fossil fuels by renewables and energy conservation, while Japan seeks for a variety of other zero-carbon fuels, like nuclear or ammonia, and sees a need for direct or indirect use of significant amounts of fossil fuels, which puts a higher priority on Carbon Capture and Utilization or Storage (CCUS). However, policies and programs that overlap in terms of the decarbonization strategy can be identified in both Japan and Germany (as well as in the EU).

Table 1 summarizes similarities and differences between Germany and Japan regarding their strategies against the energy crisis. Japan places the highest priority on energy conservation and renewables, just like Germany. But by considering the short-to mid-term necessity of fossil fuels and challenges of significant improvement of energy efficiency and limited potential of renewable supply, Japan is also planning to continue using fossil fuels directly (with CCUS) or through imports of blue hydrogen or ammonia, and therefore needs a strong “decarbonization of fossil fuels” strategy. In addition, Japan seeks for utilizing nuclear power as a substitute for fossil power generation. Germany (like the EU) is more focused on the accelerated reduction of fossil fuels by renewables and energy conservation. Induced by the energy crisis, In Germany and the EU, the ambition in the targets for energy efficiency and renewables has even been increased, aiming for synergies between energy sovereignty and climate mitigation. However, on the other hand, steps have been taken for the massive expansion of LNG terminals and for diversification activities with regard to fossil energy supply sources, which raise questions of climate-relevant lock-ins and of compatibility with the climate protection goals.

On the surface, the strategies of Japan and Germany appear to be very different, but it could be argued that, in reality, there are more common challenges. Firstly, both countries put priority on energy and resource conservation as well as the supply of renewable energy sources. Secondly, both need to use fossil fuels as a transitional pathway to a carbon neutral society, and thus have to take actions to ensure security of supply. One difference may lie in whether or not there is confidence for building the future energy system completely based on energy conservation and renewable energy, and hence the duration of the use of fossil fuels as a transitional pathway. This different perspective may be due to the geographical and geopolitical conditions in which both countries find themselves. With regard to current policy priorities, there is a clear difference concerning the role of nuclear energy.

Questions remain on whether and how Germany (the EU) can achieve ambitious climate protection goals primarily based on renewable energies and energy efficiency under changed geostrategic conditions. Japan faces the challenge of developing a decarbonization path under the special conditions of an island state that generates minimal risks in the long term and is prepared for competition on global GreenTech lead markets for renewables and energy efficiency (BMUV 2021).

Table 4-1 Similarities and differences between Germany and Japan

Similarities	Differences
• High energy prices • Mid-century net-zero targets • Finding ways forward to reach net-zero targets specially beyond 2030 • Promote energy and resource conservation • Promote renewable energies • Limited domestic resources compared to demand. (import dependence) ➢ Feedstock, synthetic fuels, renewable resources (energy carriers*) * hydrogen, ammonia, etc. • Focus on recycling	• Physical connections to other countries ➢ Germany: Power grid, pipelines ➢ Japan: No connections. Transport by ship. • Dependence on Russian gas (before crisis) • Energy mix and scenario by sector ➢ Germany: Strong emphasize on REs ➢ Japan: Various zero-carbon energies including decarbonized fossil fuel and nuclear power

5 Recommendations

Heading for the highly ambitious goal of carbon neutral societies, Germany and Japan need to work together, learn from each other, and understand each other's strengths and weaknesses. Based on the similarities and differences between Germany and Japan and comparing the strategies against the energy crisis, there are research questions which should be addressed jointly:

1. Which national technical and cost-effective potentials for energy and resource conservation and renewables exist under sustainable framework conditions and resource restrictions, and how fast can they be implemented by specific policy priorities?
2. How far do changes in social practices of using energy but also growth/rebound effects have an impact on the amount and the quality of energy consumption and what role can sufficiency policies play?
3. What are the pros and cons of options to replace fossil fuels in both countries, and what import strategies especially for green hydrogen and derived fuels can ensure economic and environmental performance?
4. If there is a need for short-term investments in fossil fuel infrastructure, can it be constructed convertible into infrastructure for hydrogen and derived fuels? To which extent will there be a need for decarbonization of fossil fuels in the medium term, to achieve long-term climate goals?
5. According to several studies (UNEP; IRP 2020; Pauliuk 2021; Acatech 2021), ambitious climate mitigation targets can be reached easier by integrating Circular Economy strategies. How can this policy integration be adopted in both countries?
6. How can the structural economic change and the developments of technologies, systems, infrastructure, etc. for carbon neutrality be accelerated and how can it be managed as a just transition and accepted by the broad public?
7. Can the gap between government climate mitigation targets and their achievement in reality be closed by legally binding targets and stronger governance, and what specific actions and management tools are needed up to 2030 and beyond?

While analyzing and comparing these national options and actions for both countries, the global frame conditions, technology markets, and trade agreements should be considered. For example, renewable energies and batteries are being developed around the world, and their costs are falling rapidly. Energy carriers such as hydrogen and synthetic fuels are closely related to renewable energies, so it is important to approach national potentials and relations to import/export countries and regions proactively by an ecological industrial policy.

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