令和２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事業調査

報　告　書

2021 年 3 月

一般財団法人日本エネルギー経済研究所

目次

第 1 章　日独エネルギー変革評議会の運営

1.1 背景

2018 年 7 月に第 5 次エネルギー基本計画が閣議決定された。2030 年に向けては徹底した省エネ、再エネの最大限の導入、火力発電の高効率化に取り組むことで、原発依存度を可能な限り低減させるというこれまでの基本的な方針を堅持し、エネルギーミックスの確実な実現を目指す方針を定めている。2050 年に向けては、パリ協定発効に見られる脱炭素化への世界的なモメンタムを踏まえ、エネルギー転換・脱炭素化に向けた挑戦を掲げ、あらゆる選択肢の可能性を追求していくこととした。これを踏まえ、将来的に最適なエネルギーシステムを実現していくためには、複線的なシナリオを設計しながら、国内外の最新情勢を常に把握し、必要な見直しを行う柔軟さと技術革新に果敢に挑戦していくことが必要である。

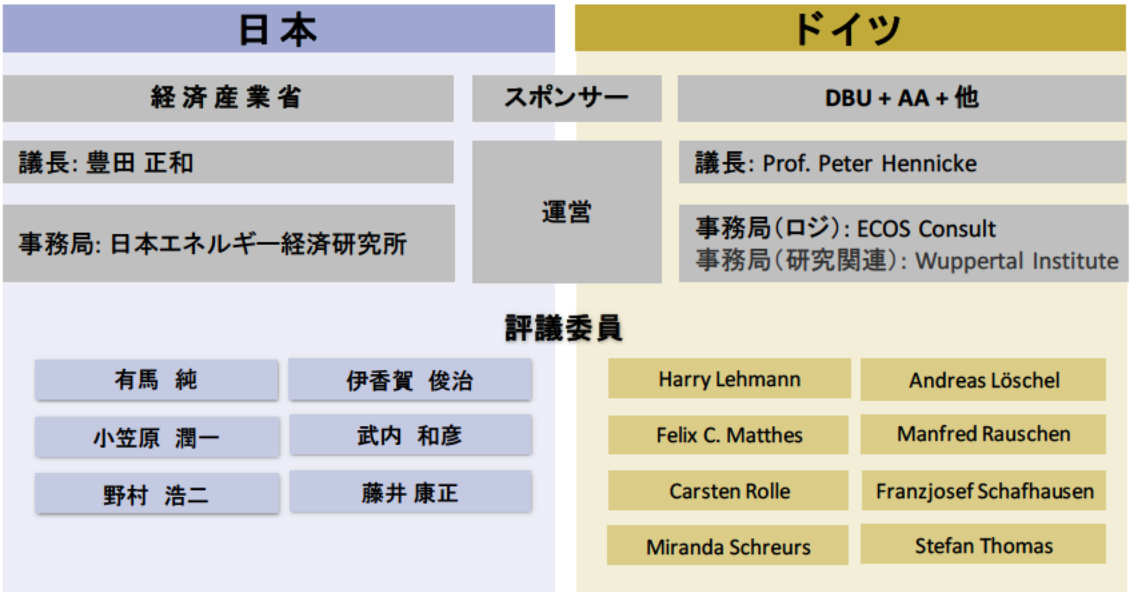
ドイツでは 2010 年に中長期エネルギー供給の在り方を示した「エネルギー・コンセプト」を決定し、現在は、省エネルギーと再生可能エネルギーの利用拡大によって 2050 年までに温室効果ガスの排出量を 80%から 95%削減するという目標を掲げ、エネルギー転換に取り組んでいる。立場の違いはあるが、同様にエネルギー転換に取り組むドイツと二国間協力を進めるべく、資源エネルギー庁では、2016 年に日本及びドイツのエネルギー専門家からなる日独エネルギー変革評議会（日独評議会）を設置し、再生可能エネルギー・省エネルギー等の両国で共通する政策課題を中心に議論を深め、日本のエネルギー政策を企画・立案するうえで必要な情報調査・収集を行ってきた。

令和元年度の評議会では、エネルギー転換の推進に向けたキーテクノロジーであるデジタル技術や水素、また昨今の再生可能エネルギー導入拡大を踏まえた変動性再生可能電力の系統接続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、具体的にはデジタル技術の活用が見込まれる分野のビジネスモデルや市場環境の整理、カーボンリサイクル技術の適用による産業部門の低炭素化、新たな不確実性としてコロナウィルス問題のエネルギー転換への影響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

評議会の構造は次のとおりである。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。



50 音、アルファベット順。敬称略。

AA: ドイツ連邦外務省、DBU: ドイツ連邦環境・資源保護・建築・原子力安全省

出所：筆者作成

図 1-1　評議会の構造

日本とドイツの共同議長、および評議委員は次のとおりである。幅広い議論を行う目的から、それぞれ専門分野が異なる者を選任している。

表 1-1　評議会のメンバー

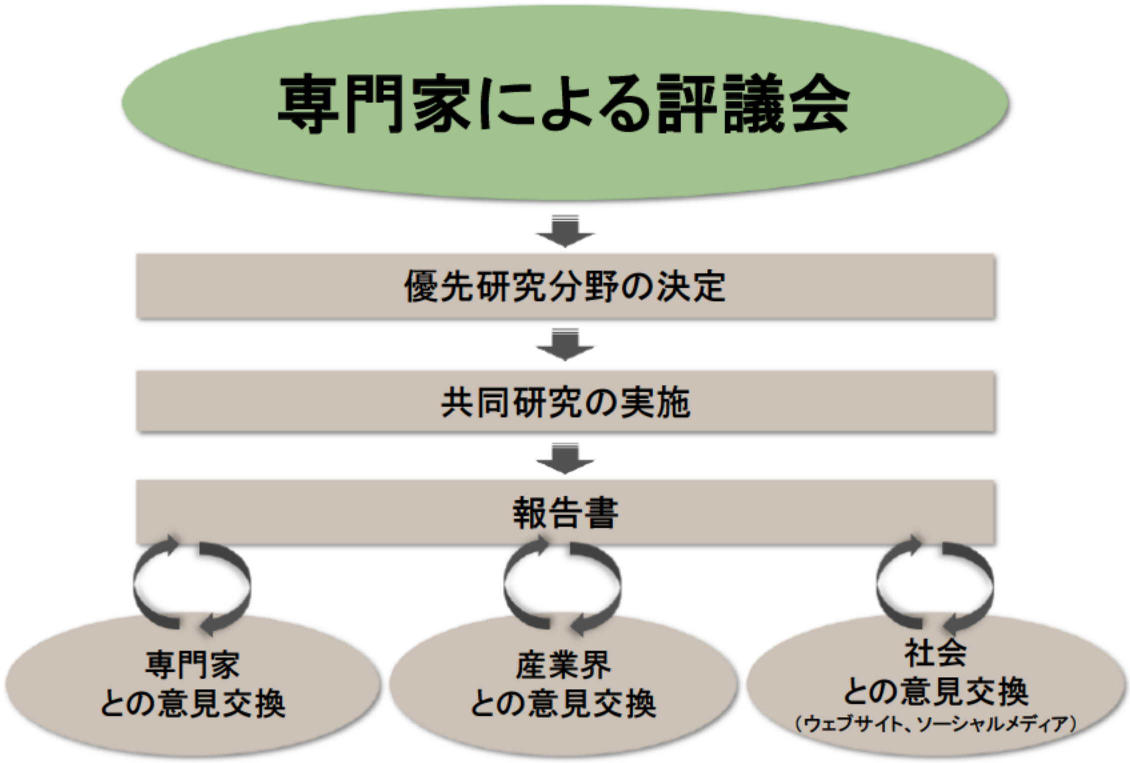
共同議長	
豊田　正和	日本エネルギー経済研究所
Peter Hennicke	Hennicke Consult
評議委員	
有馬　純	東京大学
伊香賀　俊治	慶応大学
小笠原　潤一	日本エネルギー経済研究所
武内　和彦	地球環境戦略研究機関
野村　浩二	慶応大学
藤井 康正	東京大学
Harry Lehmann	Federal Environment Agency
Andreas Löschel	University of Münster
Felix C. Matthes	Öeko-Institute
Manfred Rauschen	Öko-Zentrum NRW
Carsten Rolle	Federation of German Industries (BDI)
Franzjosef Schafhausen	formerly Federal Ministry for Environment, Nature Conservation, Building & Nuclear Safety
Miranda Schreurs	Bavarian School of Public Policy; Technical University of Munich
Stefan Thomas	Wuppatal Institute for Climate, Environment and Energy

50 音、アルファベット順。敬称略。

出所：筆者作成

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：筆者作成

図 1-2　評議会の実施事項

2020 年度は次の活動を行った。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、日独政府が行う議論の支援も実施した。

表 0-1　2020 年度の活動実績

	開催時期	内容
評議会（その１）	2020 年 6 月	コロナ禍の影響の議論 2020 年度活動内容の議論
ウェビナー	2020 年 7 月	2018 年度/2019 年度成果の披露 コロナ禍の影響分析の報告
評議会（その２）	2020 年 9 月	2020 年度研究の議論
評議会（その３）	2021 年 3 月	2021 年度研究成果の議論 今後の展開の可能性の議論

出所：筆者作成

1.4 研究分野

評議会が選定した優先研究分野は、「デジタル化とエネルギー変革」「CCUS や水素を活用したエネルギー多消費産業の脱炭素化」「コロナ禍以降のエネルギー／気候政策」の 3 つである。研究の目的は、日独両国が互いの経験や取り組みから学び合うことで、今後、それぞれが自国のエネルギー変革の達成を目指すうえで有意義な示唆を得ることにある。そのため、両国が共通して高い関心を持つ分野が選ばれている。

研究は日独の事務局が共同で作成した。報告書の作成では、全ての評議委員が参加する評議会における議論の結果も反映した。

デジタル化とエネルギー変革 AI や分散型エネルギーのビックデータなどデジタル技術を活用した送電運用の最適化

（Digitalization and energy transition: Use of digitalization to optimize grid operation utilizing AI and Big Data collected from DERs）

今後再生可能エネルギーによる分散型エネルギー供給が増えることで、それらが接続する送配電網には従来と異なる潮流と混雑の発生することが見込まれる。IOT とそれによって得られるビックデータや予測技術、AI など様々なデジタル技術を活用することによって、需給両面で分散型エネルギーを最適化し、同時に電力の安定供給を維持することが期待されている。日独ではこれをも目的とした研究や実証が行われているが、最新のプラクティスや浮かび上がってきた課題を相互に学ぶことで、各々の国におけるこうした技術の社会実装の加速に貢献することが期待できる。

CCUS や水素を活用したエネルギー多消費産業の脱炭素化

（CCUS and Hydrogen Contributing to Decarbonization of Energy-intensive Industries）

産業の脱炭素化は、大量のエネルギーを必要としたり、利用するエネルギーの電力への転換が困難であったりするなど、課題も抱えている。CCUS やグリーン／ブルー水素の利用は産業分野を脱炭素化する有望な選択肢の一つであり、日独ではその可能性が探られている。例えば、CCUS による合成燃料の製造や化学品や建築材料への炭素の固定化、グレー水素のグリーン/ブルー水素への転換、水素の天然ガス網への混入などである。日本とドイツは各々が得意とする分野で世界最先端の研究開発と実証を進めており、これらの経験を学び合うことで、産業分野の脱炭素化の加速に貢献することが期待できる。

新型コロナウィルス後のエネルギー／気候政策

（Energy / Climate policy in the post COVID-19 era）

新型コロナウィルスは日本とドイツの経済はもちろん、エネルギー／気候分野にも様々な影響を及ぼしている。人々の行動様式や働き方の変化は石油を中心にエネルギー需要の、ひいては CO2 排出量の減少という良い作用をもたらしているが、逆に将来のリバウンドが懸念される。またいずれの国も多額の景気刺激策を講じているが、これらが今後の気候変動対策にどのように影響するのかという疑問がある。あるいは、コロナ禍を契機として新たな政策の方向性が打ち出されることも考えられる。こうした新型コロナウィルスを起点として生じた変化とエネルギー転換への影響の可能性を共有することで、今後の展開を見据える視座を得ることが期待できる。

1.5 評議会の記録

ここでは、2020 年度に開催した計 3 回の評議会と 1 回のウェビナーの議題を整理する。いずれも新型コロナウィルスの影響からリモート形式での開催となった。

① 評議会その 1（2020 年 6 月 22 日）

Opening	**Welcome and brief introduction** *Welcome speeches (video messages):* *Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU)* *Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry (METI)* *Words of welcome (Co-Chairs)*
Session 1	**GJETC Report 2020:** *Short presentation of key findings and policy recommendations (15 minutes)* *Comments and Discussion (45 minutes)*
Session 2	**Integrating the Fight against the Coronavirus Crisis and Climate Change** *Presentation of joint paper* *Discussion and adoption of the paper*
Session 3	**Retrospect and further cooperation** *The GJETC as a role model of bilateral cooperation?* *Outreach activities until Oct. 2020*
Closing	**Expression of thanks and closing remarks by the Co-Chairs**

② ウェビナー（2020 年 7 月 2 日）

ご挨拶（ビデオメッセージ） 　連邦経済・エネルギー省（BMWi） 　経済産業省資源エネルギー庁
GJETC 第 2 フェーズ（2018-2019 年）の成果 ・デジタル化 & エネルギー転換 ・気候およびエネルギー政策: モニタリングと評価メカニズムの役割 ・再生可能エネルギーの統合コスト ・水素社会 ・建物のエネルギー効率化 ・輸送 & セクターカップリング
GJETC からの政策提言 （質疑応答）
コロナ危機がエネルギー変革にもたらすもの：日本の見方、ドイツの見方 （質疑応答）
二国間協力のモデルとしての GJETC と今後の展望 （質疑応答）

③　評議会その２（2020 年９月 25 日）

Opening	**Welcome and brief introduction** *Greeting address (video message) by;* *Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU)* *Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry (METI)* *Words of welcome by the Co-Chairs*
Session 1	**Possible role of scientific council and study themes** *by Wuppertal Institute*
Session 2	**Digital application to optimize distribution/transmission grid operation** *Presentation (10 min)* *Comments and Discussion*
	Short break
Session 3	**Carbon-recycling and other technologies to decarbonize energy intensive industries** *Presentation (10 min)* *Comments and Discussion*
Session 4	**Energy/Climate policy in the post COVID-19 era** *Presentation (10 min)* *Comments and Discussion*
Closing	**Expression of thanks and closing remarks by the Co-Chairs**

④　評議会その 3（2021 年 3 月 12 日）

Opening	**Welcome and brief introduction** Greeting addresses (video messages): *Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU)* *Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry (METI)* *Words of welcome (Co-Chair):*
Session 1	**Digital application to optimize distribution/transmission grid operation** *Presentation of study results (10 min)* *Discussion (20 min)*
Session 2	**Carbon-recycling and other technologies to decarbonize energy intensive industries** *Presentation of study results (10 min)* *Discussion (20 min)*
Session 3	**COVID-19 and the energy transition** *Presentation of study results (10 min)* *Discussion (10 min)*

第 2 章　政策課題への効果的な対応策の検討

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

2.1 デジタル化とエネルギー変革 AI や分散型エネルギーのビックデータなどデジタル技術を活用した送電運用の最適化

2.1.1　はじめに

本研究は、電力系統の安定化や混雑緩和を行うための分散型エネルギー資源を有効活用するためのデジタル技術（IoT デバイスによるビッグデータの AI 解析と制御等）について、日本とドイツにおける調査を行った結果をまとめたものである。ここでの分散型エネルギー資源とは配電系統に接続されている家庭用太陽光等の分散型再エネ発電設備、蓄電池、EV、非常用発電機等を指す。

VRE すなわち太陽光発電や風力発電の急速な増加や蓄電池・EV の増加による負荷変動といった大きな変化に電力系統は直面している。本調査では、デジタル技術と分散型エネルギー資源（以下、DER という）を用いて、一層高いシェアの VRE を配電系統に統合するためのビジネスモデルを扱う。分散型太陽光発電システム、蓄電池、EV、ヒートポンプ、産業プラント、ビルシステム、あるいはデマンドレスポンス（以下、DR という）として機能するスマート家電などの DER を有効に活用するためには、IoT（Internet of Things）機器による AI やビッグデータなどのデジタル技術の活用が不可欠となる。DER は配電系統に直接接続されており、DER の導入が進むことで配電系統や送電系統の混雑を引き起こす可能性がある。デジタル技術を用いて DER を柔軟性資源として有効活用するためには、配電系統運用者（以下、DSO と言う）の役割が特に重要となる。DER の柔軟性を利用することで、DSO は自らの配電系統の最適化や配電系統内での需給バランス確保、安全性と供給品質を維持することができると期待されている。併せて、配電系統事業者（以下、TSO と言う）レベルでの系統混雑の緩和についても期待されている。

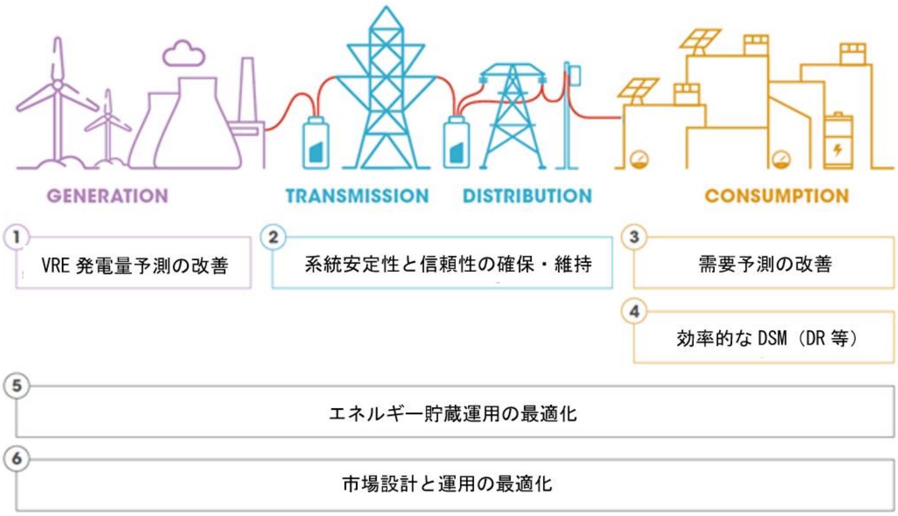
VRE それ自体は需要変動に対応できるような高い柔軟性を備えていないため、VRE のシステム統合には系統混雑を回避するための他の柔軟性オプションが必要となる。これは既に日本とドイツのいずれもが直面しつつある課題である。VRE を含む DER の需要と供給の両方の予測を改善し、DER の柔軟性を最大限に有効活用するためには、デジタル技術が不可欠となる。IoT デバイスが DER から収集したビッグデータには、各 DER の種類や接続容量、消費パターン、システムの特性などのリアルタイム情報が含まれている。具体的には、太陽光発電の発電プロファイル、EV/蓄電池の充電プロファイル、消費プロファイル、

天気予報などの情報を AI で処理し、電力市場の価格や系統の混雑状況などの他の関連情報と組み合わせて、混雑やボトルネックを回避するための最適なソリューションを提供することが期待されている。これらの技術の運用を最適化するためには、デジタル技術を十分に活用することが重要であるとの認識は既に広く定着している。

2.1.2　デジタル技術を用いた電力系統の最適化：概念的背景

本章では系統混雑を回避するために必要となる（デジタル技術を活用した）系統運用と柔軟性オプションの機能を分析した。大まかに 3 つに分類できる機能の一つが、電力需要と VRE による発電予測の改善である。また、2 つ目の機能が、電力系統の状態監視と系統の安定性と信頼性を維持するための協調的な取り組みがある。3 つ目の機能は、系統安定化のための DER の柔軟性の利用を組織化することであり、これには制御や計測などの技術的な側面と、市場・インセンティブ、選択、課金などの経済的な側面が含まれる。

図 2-1 は、高い VRE シェアの電力系統における混雑緩和に向けた柔軟な系統運用のために IoT や AI といったデジタル技術が既に採用されている（あるいは少なくとも試験運用されている）6 つの機能、すなわち VRE 発電予測の改善、系統安定化と信頼性の確保・維持、需要予測の改善、効率的な DR 等 DSM、エネルギー貯蔵運用の最適化、市場設計と運用と最適化を示したものである。



出所：IRENA 資料に筆者加筆

図 2-1　高シェア VRE の電力系統へ適用される IoT・AI 等デジタル技術の 6 つの機能

デジタル技術を通じて上記の 6 つの機能を用いて DER を柔軟性資源として活用するにはいくつかの技術的・経済的機能が必要となる。技術的な機能としては制御とモニタリングがある。DER の柔軟性を利用するためには、技術的な制御によって稼働・停止させる必要が

ある。制御は契約や金銭的なインセンティブに基づいて DER の所有者・運営者が行う場合と、系統運用者が行う場合がある。DER は遠隔/自動または手動で制御される。直接的な制御方法は柔軟性サービスの短期的な提供に適しており、特に電圧制御や混雑管理のような非常に正確な起動位置を必要とするサービスに適している。いずれの場合も、柔軟性資源の活用が発電、需要、または貯蔵に与える影響をモニタリングする必要がある。この場合、従来型メータによる負荷計測では不十分であり、負荷計測とリアルタイム伝送のためのゲートウェイを含むスマートメータリングが柔軟性の利用に必要な計測技術となる。

これらの技術的機能は、経済的機能を十分に活用するための前提となるものである。経済的機能には、柔軟性市場や DER の柔軟性を引き出すためのインセンティブ・プログラムの設計と運用、市場に対する柔軟性の提供・選択・実行、実行された柔軟性に対する支払い請求などが挙げられる。柔軟性の提供・選択については、DSO によって（あるいは DSO のために）組織された柔軟性市場を介して DER の柔軟性が確立された場合、柔軟性の事前資格認定が第一段階、DER 事業者による提供または入札が第二段階、手続きを経た柔軟性の選択が第三段階となる。制御可能な DER では、系統運用者、アグリゲータ、小売業者は、最終エネルギー需要者に所有する DER 機器の自動制御（上げまたは下げ）について同意を求めることになる。柔軟性市場を介した制御は送電系統の調整力市場での取引のように、入札および選択の段階で市場の価格シグナルを通じて行う。これらの柔軟性の利用にはすべて課金が必要であり、これはスマートメータのデータに基づいて行うことができる。

配電系統での混雑緩和に必要となる系統運用と柔軟性活用に必要とされる機能とそれらに対応するデジタル技術は以下の表にまとめられる。

表 2-1　配電系統での混雑緩和に必要となる系統運用と
柔軟性活用に必要とされる機能と対応するデジタル技術

配電系統での混雑緩和に必要となる系統運用と柔軟性活用に必要とされる機能	対応するデジタル技術
需要予測の改善	IoT（高い時間粒度でのスマートメータ・データ収集）とパターン認識と予測改善を行う
風力と太陽光発電量の予測改善	IoT（高い時間粒度での発電と気象データ収集）とパターン認識と予測改善を行う AI、必要に応じて物理アプローチ（実地形中や風車の後流中の流れの性質を記述した方程式を解くことで発電量カーブを推定する手法）を併用
系統状況のモニタリング	IoT（系統各所からのリアルタイム状況データを収集）
系統安定化と信頼性の維持	需要、発電、系統の状況データを統合して評価、AI を用いてトレンドを計算し、混雑のリスクを予測できるグリッドモデル
DERs の制御：効率的な需要と太陽光・風力発電の管理、エネルギー貯蔵の最適な運用とさらなる柔軟性	IoT（状況データを収集、DER を自動制御できる場合は DER を制御、自動制御できない場合は安全で信頼性の高い制御データを DER の意思決定者に送信）
スマートメータリング	スマートメータと安全なデータ通信（IoT の一部と解することも可能）
市場設計と運用の最適化	最適市場のための IT サーバーインフラとソフトウェア
柔軟性のオファー、選定、実行	柔軟性のオファー、選定、実行のためのプロトコルまたはスマートコントラクトとソフトウェア
支払い請求	支払い請求のためのソフトウェア（ブロックチェーン等）

出所：各種資料より筆者作成

IoT を通じた DER と系統からのリアルタイム情報収集と AI による解析がデジタル技術の中心となる。それに加えて、市場設計と運用のための IT インフラ、DER の柔軟性を市場に提供、選定、実行するためのスマートコントラクトやソフトウェアも不可欠な要素となる。次に、系統混雑を回避するために必要な系統・柔軟性運用の機能と、これらの機能のビジネス/市場モデルに関連するアクターの役割を以下にまとめる。

表 2-2　系統混雑を回避するために必要な系統・柔軟性運用の機能と
これらの機能のビジネス/市場モデルに関連するアクターの役割

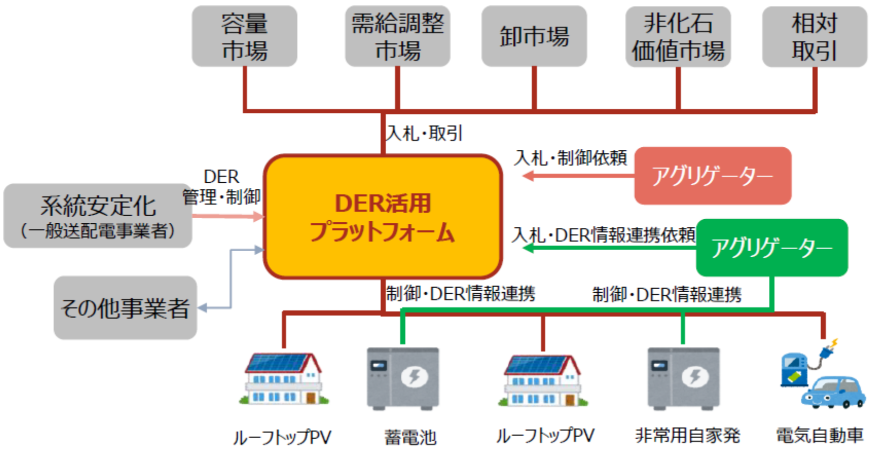
系統混雑を回避するために必要な系統・柔軟性運用の機能	各機能のビジネス/市場モデルに関連するアクターの役割
需要予測の改善	・消費者：電気使用量への課金を最適化 ・TSO・DSO：系統状況の予測、系統の安定化と信頼性の維持 ・TSO：調整力市場での調達最適化 ・アグリゲータ：発電と柔軟性利用の最適化 ・発電事業者：発電量の最適化 ・小売電気事業者：調達ポートフォリオとバランシンググループの最適化
風力と太陽光発電量の予測改善	・発電事業者：収入と収益の最大化 ・TSO・DSO：系統状況の予測、系統の安定化と信頼性の維持 ・TSO：調整力市場での調達の再低下 ・アグリゲータ：発電と柔軟性利用の最適化 ・小売電気事業者：調達ポートフォリオとバランシンググループの最適化
系統状況のモニタリング	・TSO・DSO：系統状況の予測、系統の安定化と信頼性の維持
系統安定化と信頼性の維持	・TSO・DSO：系統の安定化と信頼性の維持
DERs の制御:効率的な需要と太陽光・風力発電の管理、エネルギー貯蔵の最適な運用とさらなる柔軟性	・DER 所有者：収入と収益の最大化 ・アグリゲータ：収入と収益の最大化 ・TSO・DSO：系統の安定化、混雑緩和、信頼性の維持
スマートメータリング	・スマートメータ運用者
市場設計と運用の最適化	・市場運用者：市場を創設・運営する権利を有する、または認定された事業者が市場運営（場合によっては私設電力市場） ・TSO：調整力市場 ・DSO：地域柔軟性市場
柔軟性のオファー、選定、実行	・市場運用者 ・柔軟性 DER の所有者：市場へ入札、実行（自動でない場合、または DSO からのインセンティブに選択的に対応したい場合
支払い請求	・小売電力事業者、スマートメータ運用者、アグリゲータ、DER 所有者等

出所：筆者作成

2.1.3　日本の事例

日本でも近年の太陽光発電の爆発的な普及によって日照条件の優れた一部のエリアにおいてローカル配電系統での混雑が発生しており、追加的な再エネの導入が困難になってきている。今後も再エネ発電や EV、蓄電池といった DER の増加は不可避と見られる。再エネの一層の導入を目指して、DER の管理・制御方式や関連するサービスを我が国に適用するための課題とその効果を整理するため実現可能性調査（フィージビリティスタディ）が 2020 年度から実施されている。現在のところ、この事例が、DER の制御を通じた潮流変化によってローカル系統の混雑解消を目的とした具体的なビジネスモデルとして唯一のケースと考えられる。

このモデルは、欧米諸国での実施事例を参考にして、送配電事業者が DER を調達・運用する DER 活用プラットフォームを構築し、それを通じた柔軟性の調達を行なうものである。DER の一層の活用を実現し、送配電系統の課題を解決するとともに、将来的にはアグリゲータの各種市場参入を容易にするなどの効果も期待できると考えられている。図 2-2 はこのモデルの全体像である。

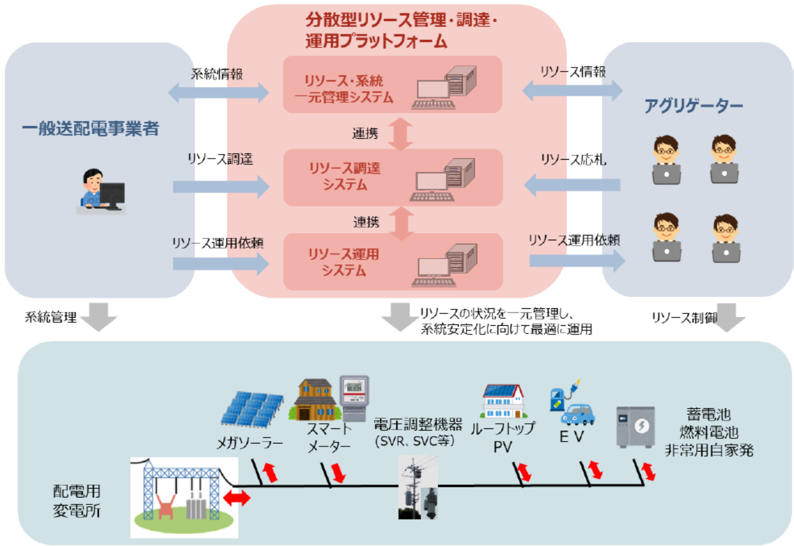


出所：経済産業省

図 2-2　日本において検討されている DER 活用プラットフォーム・モデルの全体像

このモデルの中心的な部分は言うまでもなく DER 活用プラットフォームである。配電系統で接続されている DER 群（ルーフトップ太陽光、蓄電池、EV 等）に関する情報をリアルタイムでプラットフォームに収集し、それらの情報を元に一般送配電事業者が DER 群の管理・制御を行うことが想定されている。DER 活用プラットフォームを通じて、一般送配電事業者は DER 賦存状況のリアルタイムで把握できるようになり、データ解析に基づいて制御対象となる DER の特定と制御が可能となる。併せて、アグリゲータも、DER 入札や運用の精緻化、複雑化への対応を DER 活用プラットフォームに代行させることができ、制御・運用システム投資の適正化、各市場の市場要件や通信要件への対応が容易になることが

期待されている。



出所：経済産業省

図 2-3　DER 活用プラットフォームの機能のイメージ

図 2-3 は活用プラットフォームの諸機能のイメージ図である。一般送配電事業者が DER 活用プラットフォーム（分散型リソース管理・調達・運用プラットフォーム）を通じて DER の状況を一元管理し、系統安定化に向けて最適運用することが想定されている。
このモデルは 2020 年度から検討開始されたばかりであり、具体的な成果は現時点では明らかとされていない。

2.1.4　ドイツの事例

ドイツの事例の多くは、2016 年末から政府によって開始された「Smart Energy Showcase - Digital Agenda for the Energy Transition」（SINTEG プログラム）の下での実証事業である。SINTEG プログラムは、ショーケースと呼ばれる 5 つの大きなモデル地域で構成されており、それぞれ将来のエネルギー供給のためのモデルソリューションが開発・実証されており、特にエネルギー分野のデジタル化に重点が置かれている。300 以上のプロジェクトが参加しているが、本調査では、IoT、AI 等を用いて電力系統の状態を監視・維持するための革新的なソリューションを提供しているプロジェクト、そして、地域柔軟性市場やプラットフォームを構築しているプロジェクトに着目した。併せて、DSO による DER の制御の側面にも注意を払った。以下、SINTEG プログラムから Enara プロジェクトと Windnode プロジェクトの 2 つの概要を示す（詳細やその他のプロジェクトについては本文参照）。

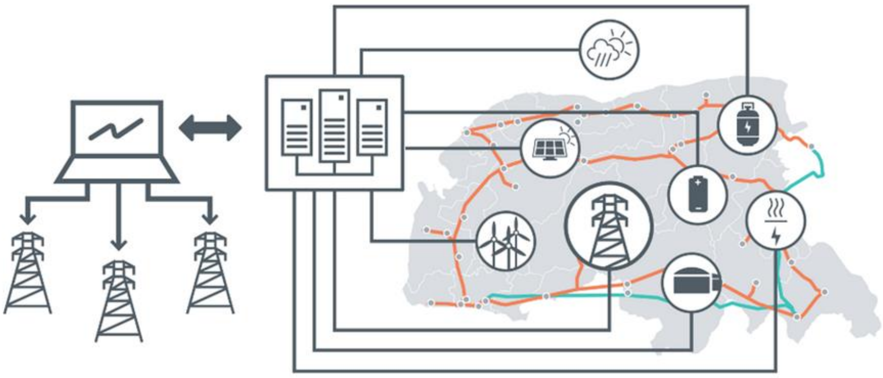
enera プロジェクト（系統状況のモニタリングと系統安定化の維持）

enera プロジェクトは大量の風力発電設備が集中しているドイツ北西部で実施されている SINTEG ショーケースである。柔軟性の可能性を評価し、実際の柔軟性を用いて系統の運用シナリオや将来シナリオを開発するためのシミュレーションプラットフォームを構築している。柔軟なエネルギー変換ユニット（太陽光発電量の変動による配電系統のインバランスを自動で安定化させる 200 のスマート変電所、配電系統の電圧維持のため風力発電にフルコンバータ設置、DER の制御、風力発電の間欠性を補うための 7MW 規模の蓄電池制御）を用いて系統混雑による再エネ発電量の出力抑制をどのように回避または削減できるかを実証している。加えて、柔軟性オプションの将来的な運用シナリオの検討も含まれている。このプロジェクトの中心は、柔軟性の可能性評価、実際の柔軟性を用いたネットワークの運用シナリオや将来シナリオの開発を行うシミュレーションプラットフォームである。

シミュレーションプラットフォームでは、例えば、強風時の風力発電送電容量の過負荷などクリティカルな送配電系統の状況に応じて送配電系統の柔軟性要件が決定される。従来は、このような状況に対して、系統運用者はフィード・イン・マネジメントによって再エネ発電量の出力を低減させて（つまり再エネの出力抑制）、系統の過負荷を回避してきた。過負荷が発生するかどうかは、現在の発電状況や負荷状況、特に送配電系統のトポロジーに大きく依存する。そのため、シミュレーションプラットフォームには、enera 対象地域の配電系統の高圧レベルの詳細なモデルだけでなく、配電系統に接続されている DER やエネルギー変換ユニットのモデルも含まれている。

シミュレーションプラットフォームで検討されている技術は、風力発電、太陽光発電、大規模および家庭用蓄電池、家庭用コジェネ、柔軟性のある給電可能なコジェネとバイオガス発電である。これらのモデルは、実際に稼働している機器の測定データや協力会社から提供された情報、メーカーや一般に公開されている情報源から得られたデータを用いて作成されている。シミュレーションプラットフォームの重要な要素は：

1）垂直方向の系統負荷のシミュレーションに基づく系統混雑に対する系統からの柔軟性需要の時間的・場所的な定量化
2）系統の混雑を回避するための分散型エネルギー変換ユニットの柔軟性ポテンシャルの量的評価
3）将来の送電網の柔軟性に対する需要を分析するためのシナリオの作成



出所：enera

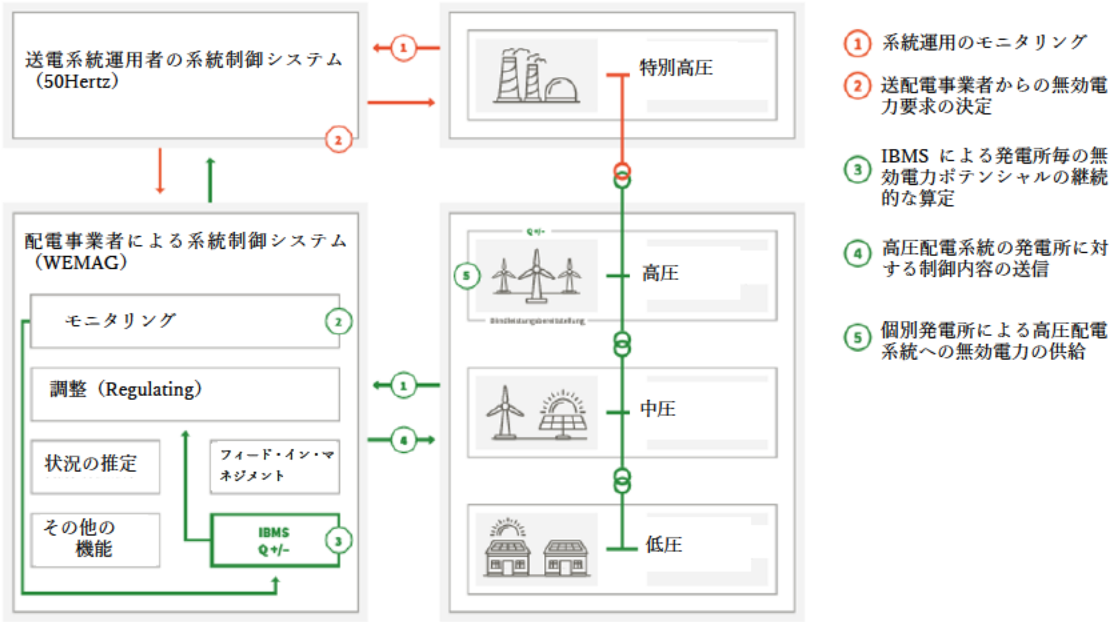
図 2-4　enara プロジェクトの全体イメージ図

Windnode プロジェクト（配電系統運用者による DER の制御）

配電系統からの無効電力を一層柔軟に供給するためには、風力発電や太陽光発電の制御が必要となる。ドイツ東部の DSO である WEMAG Grid による Windnode プロジェクトでは、配電系統や送電系統運用者からの要求に対応するための制御システムからの直接的な DER 制御の実証を行った。送配電系統運用者の要求は指定された相互接続点での無効電力量の提供であり、自動的に提供された無効電力によって定義された目標電圧が安定化される実証も含まれる。

このプロジェクトの重要な要素はネットワーク制御システムの機能拡張であり、いわゆるインテリジェント無効電力管理システム（IBMS）が含まれる。このシステムの機能範囲には、発電所の遠隔制御統合、ノード固有の無効電力ポテンシャルの算定、配電系統または送電系統からの要求に応じた直接的な無効電力制御指示の送信、制御ポテンシャルの可視化が含まれる。

IBMS の無効電力制御に発電所が参加するためには、事前に参加資格の認定を受ける必要がある。参加可能性のある発電所に対する集中的なテストを行うことで参加資格を得た発電所のストックを拡大させた。プロジェクト終了までに、DSO の高圧系統に接続されているすべての発電所をシステムに組み込むことで、配電系統からの制御のポテンシャルは最大化される。このプロジェクトでは、分散型再エネ発電を配電系統で利用することに重点を置いているため、送電系統は制御の対象外となっている。下図はこのプロジェクトの WEMAG Grid 系統制御システムにおけるインテリジェント無効電力管理システム（IBMS）のプロセスの流れを図示したものである。



出所：Windnode 資料に筆者加筆

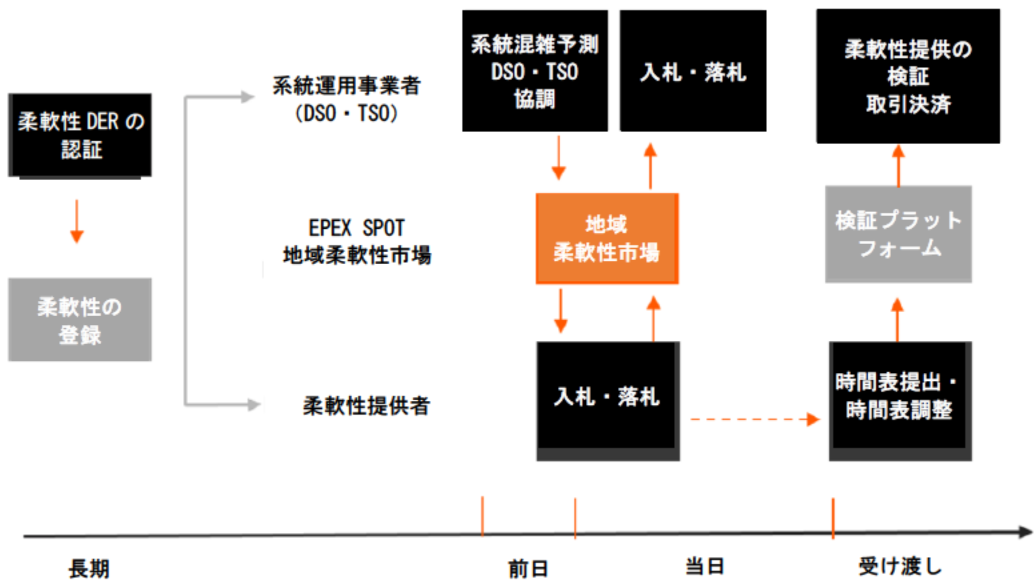
図 2-5　Windnode プロジェクトでのインテリジェント無効電力管理システム（IBMS）のプロセスの流れ

enera プロジェクト(地域柔軟性市場とプラットフォームの構築)

現在のところ、系統運用事業者は系統混雑を解消するために、主として（法律で定められた）非市場的な手段を用いている。系統操作などのコスト中立的な対策に加えて、再給電指令やフィード・イン・マネジメント（系統運用者が系統容量不足を回避するために遠隔制御装置を備えた再エネ発電設備を技術的に管理すること：典型的な事例は発電所に対する出力制御）といった対策が行われている。系統混雑を積極的に回避して一層の再エネを系統に接続させるには、地域における追加的な柔軟性資源を開発する必要がある。こうした中、近年のデジタル化技術の急速な進歩によって、ローカル配電系統に接続されている分散型発電、消費者、蓄電池といった DER がエネルギーシステムに積極的に参加して、DER の柔軟性を提供することが技術的に可能となった。しかしながら、系統運用者がこうした地域の柔軟性を適切に活用する環境は整備されていなかった。

地域 DER の柔軟性資源としてのポテンシャルを有効活用するために、SINTEG の enera プロジェクトにおいて、取引所として組織された enera 柔軟性市場（「enera Flexmarkt」）の開発・実証が行われた。EPEX SPOT は、enera Flexmarket の市場設計をベースに、enera marketplace の設計、開発、実装、運用を行った。2019 年 2 月 4 日から 2020 年 6 月 30 日まで、柔軟性市場コンセプト全体、特に市場の実証フェーズが実施された。実証期間を通じて、6 つの柔軟性プロバイダー、2 つの DSO、1 つの TSO が参加した市場が安全かつ効率的に運営され、合計で 4,000 件以上の入札が送信され、130 件の取引が成立した。なお、こ

うした地域柔軟性市場の設立・運用はドイツではまだ一般に認可されておらず、SINTEG プロジェクトは規制対象外の実験として例外的に認められた。下図は enara 地域柔軟性市場（短期市場）における時間経過に伴う一連の取引の流れを図示したものである。



出所：EPEX SPOT 資料に筆者加筆

図 2-6　enara 地域柔軟性市場（短期市場）における時間経過に伴う取引の流れ

図 2-6 で示した地域柔軟性市場の取引の流れは以下の通りである。

- 最初に、柔軟性市場に参加するための承認として、DER を接続している系統運用事業者が個々の柔軟性プラント（DER）にワンタイム認証を発行。
- 系統運用事業者は、系統混雑を当日市場の範囲内で可能な限り早期に検出して混雑の結果として生じる柔軟性資源への需要量を事前に判定するために、他の系統運用事業者と協調して系統混雑を定期的な頻度で予測。系統運用事業者は、取引プラットフォーム上で必要とされる柔軟性の要件（必要量、時間条件等）と支払い意思を表明。
- 同様に、市場参加者は取引プラットフォーム上にアベイラブルな柔軟性と提供価格を表明。
- 取引プラットフォームは柔軟性に対する需要と供給を比較し、その後、両方の入札に互換性がある場合に取引のマッチングを市場参加者に通知。注文照合ルールにより、システムでアベイラブルなベスト価格で注文を実行。柔軟性の提供者には、スペックに従って柔軟性を提供する義務が発生。
- 柔軟性が提供されると、電力系統に物理的な影響が生じて、系統混雑は解決または緩和。検証プラットフォームプロセスの一部として、柔軟性の発生ポイントでのモニタリングデータに基づいて、柔軟性の提供について系統運用者によって事後検証、その後、取

引決済。

2.1.5　事例を踏まえた日本とドイツに対する政策的インプリケーション

日本については唯一の事例と考えられる実現可能性調査の結果が得られていない現時点では、事例考察からの政策的インプリケーションの導出は時期尚早と考えられる。しかしながら、ドイツの事例（後述）から得られる示唆として以下が考えられる。現状の実現可能性調査で検討されているDER活用プラットフォームに関する検討は主として技術的側面に焦点が当たっていると見られるが、ドイツの事例に対する考察は、技術的側面と並行して経済的な側面の検討を深めておくことの重要性を示唆している。ここでの経済的側面とは、例えば、DER の活用を促すための価格シグナルの形成とそれを実現するための地域柔軟性市場の形成である。技術的側面が満たされても、経済的な側面の確立が伴わない限り、検討されているビジネスモデルが実現することは困難であるという至極当然の帰結がドイツの事例から明らかとなっている。同様に、ドイツの事例から、DER の柔軟性ポテンシャルを引き出すには電力システムや市場に対する規制緩和が不可欠であることも明らかとなっており、これも日本にも同様に適用できると考えられる。

次に、ドイツの事例考察から導出された政策的インプリケーションは以下の通りである。

- 配電系統の最適化のために DER の柔軟性を活用することは技術的には可能であるが、現状のドイツでは DER の柔軟性が十分に活用できる環境が整備されていないため、そうした環境（regulatory environment）を政策的あるいは規制的に形成することが必要である。その上で、DER の柔軟性を当日市場での価格シグナルを通じて提供するのか、その場合、DER 所有者による制御なのか、配電事業者による制御なのか、あるいは、地域柔軟性市場を通じて提供するのかについて制度設計にあたって決定しておく必要がある。要するに、DER の柔軟性を（技術的な側面に加えて）経済的に引き出す手段は何なのかについて目的を踏まえた検討が必要とされる。ドイツの SINTEG プログラムにおいてもこれらの点についての検討は不十分であり、今回調査対象としたプロジェクトの多くも実証事業にとどまり商用化まで進んでいない。
- 地域柔軟性市場を実現するためには、柔軟性の潜在的な供給者が発電・消費プラントや蓄電池を所有することや商用ベースで送配電事業者に地域柔軟性を提供できるように、既存の規制の枠組みを緩和・改変してゆく必要がある。例えば、現状のドイツの規制においては地域柔軟性市場の設立・運用は認められていない。
- DER を活用して最適化するべき配電系統の範囲を検討する必要がある。例えば、非常に小さな区画、都市中心部、周辺エリアも含んだ都市全体、あるいは DSO の配電エリア全体など最適化すべき範囲の決定因子はまだ不明確なままである。また、一般的な議論として、単独の配電系統内で、または配電系統の一部分だけで需給バランスを維持することは本当に可能なのか、あるいは、配電系統のバランスを維持するために必要な送

電系統との協調のレベルなどは依然として明確になっていない。既存規制の緩和・改変はこれらのテーマに関する今後の洞察結果に基づいて行われるべきである。

- また、SINTEG プログラムの C/Sells プロジェクトにおいては、今後必要とされる具体的な取り組み提案として以下が挙げられている。
  - 規制緩和によって小規模な DER の市場へのアクセスを簡素化し、新たな活動機会の提供の創出（例えば、近隣コミュニティ内、自主的な自家消費発電事業者、再エネコミュニティの中でのエネルギー取引、さらには柔軟性プラットフォームへの自主的参加による系統混雑緩和への利用など）。
  - 系統運用事業者や柔軟性提供者が系統運用への柔軟性活用に対して追加的コストを負担するのではなく、むしろ逆に系統運用への柔軟性活用に対してインセンティブを付与できるような合理的な賦課金、料金、手数料体系な設計。
  - 地域全体の柔軟性の可能性と実現可能性の分析の実施、およびドイツのすべての DSO を最終的にカバーするためロードマップの策定。
  - DER 接続のインターフェイスやプロセスの標準化、および標準化されたスマートグリッド・インターフェイスのラベルの開発。DER の柔軟性を高めるために、リレーを使わずに制御できるデジタルインターフェースを定義し、ゲートウェイを安全な通信・制御コンポーネントへと改変。

2.2 CCUS や水素を活用したエネルギー多消費産業の脱炭素化

2.2.1　水素の直接利用およびガスへの水素混合

1）ドイツ

ドイツは、水素利用の主要な分野として産業部門に焦点を当てた国家水素戦略を 2020 年に公表した。水素は、素材産業、特に鉄鋼や化学産業を脱炭素化するための重要なツールとされている。そのため、国家水素戦略は、再エネ由来のグリーン水素に注目し、国内で水電解装置の規模拡大を目指す。しかし、ドイツ国内では再エネのポテンシャルも限定的なため、国家水素戦略では、グリーン水素の輸入も考慮している。この方針は、EU 域内で 40GW および EU 隣国で 40GW の水電解装置の導入を目標とする EU の水素戦略も反映している。

バリューチェーン（生産、輸送、利用を含む）の各過程に注目し、素材産業の関係部門において大規模な RD&D が実施されている。しかし、様々な課題が待ち受けている。とりわけ、他の水素と比較した場合のグリーン水素のコストである。これは、天然ガスやブルー水素分野における開発（および政策決定）によってグリーン水素の可能性や利用が左右されることを示唆している。さらに、技術、インフラ、規制に関する課題も解決されなければならない。従って、国家水素戦略は政策的なイニシアティブを提示している。

産業プロセスにおけるガスへの水素混合は国家水素戦略ではあまり言及されていない。ガスへの水素混合はドイツの既存のガスインフラネットワークを利用する機会でもある。しかし、水素の混合割合によって、ネットワークの改修（および、投資）を伴う。一般的に、ガスへの水素混合は、むしろ、熱部門を脱炭素化する選択肢として見られている。そのため、省エネ向上や電化といった代替方法がある部門でのガスへの水素混合は、貴重な水素の浪費にもなりうる。他方、産業部門は他の選択肢が限られている。産業部門によっては、ガスへの水素混合は、機会として捉えるよりも、グリーン水素の不足をもたらし、価格高騰につながると不安視している。

2）日本

日本は他国に先立って水素に関する政策方針を示した。水素・燃料電池戦略ロードマップ（2014 年策定、2016 年・2019 年改訂）および水素基本戦略（2017 年）は、水素発電、燃料電池自動車、家庭用燃料電池（エネファーム）の推進を掲げている。産業部門における水素利用についてはあまり検討されてこなかったが、2019 年水素・燃料電池戦略ロードマップにてその可能性について言及された。2020 年 12 月、日本はグリーン成長戦略を発表した。同戦略は、2050 年までにカーボンニュートラルを達成するために脱炭素化の技術を取り上げ、水素は産業部門の脱炭素化に必要な技術と位置付けられている。

日本では、水素のサプライチェーンの各部門に関して様々な実証事業を行っている。経済産業省は比較的大規模な実証を支援し、環境省は地方自治体と連携して、水素の地産地消となる小規模な実証を推進している。ただしこれらは、産業部門のみならず、運輸や民生等の

他部門を含んでいる。

産業部門での水素の直接利用に関する取り組みとして、日本鉄鋼連盟が革新的な製鉄プロセス技術開発として COURSE50（CO2 Ultimate Reduction in Steelmaking Process by Innovative Technology for Cool Earth 50）を実施している。このイニシアティブは 2030 年までに製鉄工程で CO2 排出量を 30%削減し、2050 年までに当該技術の実用化および普及を目指している。産業部門は低炭素化の努力を行っているが、技術的な障壁はまだ高く、引き続き研究開発（R&D）が必要である。また、もう一つ重要な課題として、水素を産業用需要家に輸送するためには、専用のパイプライン（インフラ、ネットワーク）が必要とされているが、その開発には経済性が課題となっている。

なお、既存都市ガスインフラへの水素混合も議論はされているものの、その実現可能性については、技術的、制度的、経済的観点から否定的な意見が多い。そのため、ガス業界等は、水素ではなく、既存のガスインフラや機器への影響が少ないカーボンニュートラルメタンの混合を主軸に考えている。ガスインフラを脱炭素化する戦略を明確にするために（どの低炭素化されたガス（水素やカーボンニュートラルメタン等）を使うのか等)、将来の部門別需要構造や経済性を踏まえながら、さらなる議論が必要である。

2.2.2　CCUS

1）ドイツ

ドイツにおける CCUS の議論は個別に行う必要がある。まず CCS についてであるが、陸上の CO2 貯留（CCS）は深刻な社会的受容性の問題がある。これは、当初 CCS が発電所を対象に検討されたこと、また、CCS による影響（例えば地下水への影響）が不明であることに起因する。従って、CCS の議論は、洋上での貯留および産業施設からの CO2 分離回収に移行した。次に、CCU については注目が高まっており、RD&D 事業に対するかなりの資金支援が行われている。産業施設から分離回収された CO2 の利用方法として、特に、短命の（short lifespan）製品に用いられている。特に、ドイツのセメント産業が CO2 分離回収に注目している一方で、化学部門でも CO2 利用の試験や実証が行われている。

CCU を支援する政策措置はとられているが､総合的なロードマップは策定されていない。国家水素戦略では水素経済に伴う開発として CCU の役割を容認している。

ライフサイクルアセスメントに関する議論は始まったばかりであるため、CCUS が直面する懐疑的な見解（技術的な不確実性も要因）は別として、他にも市場での普及を遮る障壁がある。水素分野の水電解装置のように、炭素回収技術は膨大なグリーン電力を必要とする。そのため、ドイツ国内での再エネ発電量の制約が主なボトルネックと考えられ、CCUS 技術におけるエネルギー量を削減する必要性が指摘されている。また、CO2 分離回収に対する需要は大規模な CO2 輸送インフラ構築が不要な産業地域（CO2 の排出から回収までが比較的短い距離となる地域）に限られているため、現時点では限定的である。CO2 輸送が長距離になるとインフラや関連の投資が必要となる。インフラがなければ、ステークホルダー

は不確実な投資の実現には興味を示さないであろう。

２）日本

CCS は大規模な CO2 排出量削減のポテンシャルがあると認識される一方、日本では気候変動対策の効果的な手段として CCU に対する関心が高まっている。特に、CO2 を原料として利用するカーボンリサイクルの機運が高まっている。カーボンリサイクル技術によって生産される化学品や燃料によって、産業プロセスや輸送部門において従来用いられていた化石燃料に代替することでこれら部門の脱炭素化を進めることが期待されている。

日本政府は CCS とカーボンリサイクルを中心とした CCS を様々な政策によって推進している。中でもカーボンリサイクル技術ロードマップ（2019 年 6 月）は、化学品、燃料、鉱物といった主要な分野において可能性のあるカーボンリサイクル技術の商業化を目指す方向性を示している。また革新的環境イノベーション戦略（2020 年 1 月）は、カーボンリサイクル・CCUS 技術を重要領域の一つとして掲げている。最新の政策であるグリーン成長戦略（2020 年 12 月）では、グリーン成長のポテンシャルがある産業としてカーボンリサイクル事業の推進が明示されている。

日本では CCUS 技術の RD&D を支援するために政策的な支援を実施してきた。CCS では、2012 年度に苫小牧（北海道）で初の大規模実証を開始し、2019 年 11 月に目標であった CO2 貯留 30 万トンを達成し、今後の課題も確認されて 2020 年度に終了している。カーボンリサイクル技術に関する RD&D プロジェクトも積極的に行われている。例えば、大崎上島町（広島県）は、カーボンリサイクル実証研究拠点として整備され、横断的な研究や技術開発が行われる。さらに、日本では、生産過程で CO2 を利用する CO2-SUICOM というコンクリートがすでに商用化されている。

CO2 排出削減について CCUS 技術に対する期待が高まる中、ほとんどの技術はまだ初期段階であるため、様々な課題の克服が求められる。まず、商業性が予見できなければ、民間部門は CCS やカーボンリサイクルへの投資を躊躇する。そのため、RD&D の推進や必要なインフラ開発において政府の役割が重要となる。CO2 回収コストの削減、CCS の CO2 貯留における安全性や信頼性の確保、CO2 を活用した製品の商用化において、技術開発がカギを握っている。国・自治体、産業界、大学・研究機関による協力によって技術革新の促進が期待される。最後に重要なこととして、適切な規制枠組みを確立しなければならない。CCS は既存の法制度を補う規制が必要である。カーボンリサイクルについては、技術の有効性を証明するためにも、CO2 のライフサイクルアセスメントに関する国際的な規制作りが重要と考えられる。

2.2.3　主要な結論

産業部門の脱炭素化はドイツおよび日本にとって共通の課題である。両国は、産業部門における水素利用を推進する政策枠組みを策定し、水素のサプライチェーンに関する RD&D

を促すための支援を提供している。ドイツは水素の直接利用に関する大規模な RD&D 事業で先行している。一方、日本では、産業部門の大規模な水素利用の実証事業は限定的で、地方自治体における輸送・民生部門における水素利用に関する小規模事業が中心となっている。両国にとって、水素の生産および（船舶による）輸入コストは主要な課題となっている。消費者への水素配送に関して、ドイツは、ガスへの水素混合は、実現する前に様々な課題をクリアする必要があるが、既存のインフラを活用する機会と捉えている。しかし、日本は、ガスインフラがドイツ程拡充されていない、既存のガスインフラや技術に対する水素混合による影響の詳細な調査や長期的な戦略が欠如しているため、水素のガスへの混合はあまり議論されていない。

ドイツと日本は、CCS に関して、社会的受容性（特にドイツ）や限定的な可能性といった類似の障壁に直面している。そのため、両国は CCU の検討に動いており、特に日本はカーボンリサイクル技術を注視している。しかし、両国において、CCU のライフサイクルアセスメント、CCU を使った製品の市場性、CO2 インフラの開発といった課題も認識されている。

2.3 新型コロナウィルス後のエネルギー／気候政策

2.3.1　新型コロナウィルスの影響

2020 年は世界全体の経済が大きく落ち込み、日本とドイツも影響を免れ得なかった。エネルギーでは特に石油需要の落ち込みが大きく、WTI 原油価格は歴史上初のマイナス価格を記録することも起こった。

１）日本

日本では、2020 年第 2 四半期の GDP が前期比-8.4%と大きく落ち込んだ。これは 2008 年から 2009 年にかけての金融危機の際にも経験しなかった規模である。この背景には、感染対策を目的として人々の行動が大きく制限されたことがある。政府は 2020 年 4 月に東京他 7 府県に緊急事態宣言を発し、5 月 4 日に適用が全国に拡大された。その結果、人々は接触を回避するために外出を控え、また人が集まりやすい大型の店舗に行くことを回避し、逆にデジタルコンテンツやネットショッピングを多用するようになった。移動手段では、密集の可能性のある公共交通機関が忌諱され、逆に自動車や自転車などパーソナルモビリティを好む傾向がみられた。更には、住まいの場所にも変化の兆しがみられた。例えば東京では、2020 年 7 月から 4 か月連続で人口の流出超過となった。

ビジネススタイルにも変化が起こった。海外出張はほぼ消失し、国内出張も大きく減少した。政府の調査によると、業種によって利用率は異なるものの、およそ 1/3 の人々がリモートワークを経験した。地域別には特に東京での利用率が高く、通勤時間の短縮効果から、経験者の多くは継続を望む結果となっている。

産業活動は、2020 年 4 月から 5 月頃に欠けて大きく落ち込み、その後回復する傾向にある。産業は投資サイクルが永く、短期間で劇的な構造転換を行うことは出来ない。そのためコロナ禍の影響を見定めるにはもう少し時間を要する。一方、国内外のサプライチェーンの破断など、事業継続計画（BCP）のリスクを浮き彫りにした。そのため企業はサプライチェーンの多様化や内製化、在庫管理の見直しなど、BCP 強化に向けた取り組みを進めている。

エネルギーでは、ガソリンとジェット燃料の落ち込みが最も大きかった。逆に、軽油やナフサ、天然ガス、電力は消費量の落ち込み自体が小さいことに加え、回復も早かった。

２）ドイツ

コロナ禍以前は 2020 年の CO2 排出削減目標（1990 年比 40%削減）の達成が危ぶまれる状況であったが、コロナ禍を要因とした運輸と産業におけるエネルギー消費量の減少から、目標の超過達成（42.3%減）となった。エネルギー別には石炭、原子力、石油が前年比で大きく低下した一方、天然ガスはわずかな減少にとどまり、再生可能エネルギーは増加しさえした。逆に、景気が回復した後のリバウンドが懸念されている。

ドイツでは厳しい都市封鎖が講じられた。2020 年春に学校や大部分の商店や飲食店が閉

鎖されたほか、二人以上の集合の回避、多くのイベントの中止、旅行の自制が行われた。感染者数の変化に合わせた程度の差はありながらも、コロナ禍は人々の生活を大きく変えた。

生産量の低下が続き、コロナ禍は産業に従来にない規模の圧力を与えることとなった。ドイツの産業は世界のバリューチェーンに組み込まれており、世界中で蔓延した新型コロナウィルスの影響を強く受けて国内外の売り上げが減少した。業種別には自動車や機械・プラントエンジニアリング、航空・旅行が最も大きな落ち込みとなり、多くの産業はサプライチェーンの破断に苦慮した。雇用面でも、休業が従来にない規模で行われ、所得を保証するための支援が 2021 年 12 月まで継続されることとなった。

一般家庭の約 4 割が収入低下や資産減少の悪影響を受けたと言われ、これが個人消費を慎重にさせている。店舗の営業が規制されたことからオンラインによる購買行動と、それに伴う配送用の交通量が大きく増えた。またプラスチックなど家庭ゴミも増えている。一方、生活や消費が都市中心部から住まいの近隣に移ることが見られる。移動手段では、自家用車や自転車が好まれ、逆に公共交通やカーシェアは忌諱される傾向にある。

働き方では、それまでは稀であったリモートワークの利用が 61%にもなった。また業種や会社の規模によって異なるが、ビジネスのデジタル化が進んだ。経営者の多くはビジネスのデジタル化と出張の抑制を維持するとしており、コロナ禍終息後も物理的な移動がデータ通信に置き換えられることが定着すると考えられる。

2.3.2　景気刺激策とエネルギー転換

コロナ禍がもたらしている社会的、経済的苦境を乗り越えるために、政府は多額の資金を投じている。しかし、コロナ禍以前の世界にも、気候変動を含む解決すべき課題は多くあった。コロナ禍対策を目的とした資金供給が、それら従来からある世界の課題に逆行するものとなれば、必要なイノベーションや経済の競争力を損なうことが懸念される。

日本では、計 3 回の景気対策が講じられた。2020 年 4 月の第一次補正予算と 6 月の第二次補正予算は医療の強化や、個人や企業の救済を主な目的とした。これに対して 2020 年 12 月の「国民の命と暮らしを守る安心と希望のための総合経済対策」では、コロナ禍への対応とともに、「ポストコロナに向けた経済構造の転換・好循環の実現」「防災・減災、国土強靭化の推進など安全・安心の確保」という柱も加わった。

このなかでは「グリーン社会の実現」として、2050 年カーボンニュートラルの実現に向けた調整を新たな成長戦略と位置づけている。これは 2020 年 10 月の菅首相による、2050 年カーボンニュートラルを目指すとの宣言を受けたものといえる。具体的には、2 兆円の研究開発基金の創設や、自動車の脱炭素化や建物の断熱強化、分散型エネルギーの利用拡大の支援、世界の脱炭素化への貢献を掲げている。

ドイツでは 2020 年 3 月と 6 月の 2 回、景気対策が講じられた。第 1 回の対策では、医療

や雇用の維持、中小企業の支援など短期的な救済を目的としたものである。第 2 回の対策はより長期の視点にたって経済対策であり、気候変動やデジタル化の視点が組み込まれている。約 500 億ユーロ（総額の 38%）が未来の技術に投じられる。気候変動に関しては、運輸部門の脱炭素化や水素、FIT 賦課金の減額補助、太陽光発電の上限撤廃、建物の脱炭素の支援を行う。

なお、ドイツの景気刺激策を見るうえでは EU との関係も踏まえる必要がある。EU は加盟国に対して景気対策予算を割り当てるが、この活用には条件が付されている。すなわち、加盟国は独自に行う景気刺激策において、総額の 37%以上をグリーン転換の理念に沿ったものとし、また気候中立を大きく損なってはならない。

2.3.3　政策への影響

1）日本

日本の政策変化では、「サプライチェーンの強化」「デジタル化」「カーボンニュートラル」の 3 つを挙げることができる。

コロナ禍は物品のみならず人材を含むサプライチェーンを破断することとなった。例えば自動車製造では、部品供給が滞ったことで生産ラインを一時的に止めざるを得ない状況となった。またヘルスケア品では、輸入量の減少から異常な高値で取引されることが起こった。これらの経験を踏まえ、輸入相手国の多様化などサプライチェーンの強化を目指す方針が示されている。

新たな社会インフラや将来の成長の基盤、あるいはサプライチェーン強化のツールとして、デジタルインフラを強化する方針が、コロナ禍を経てより強化された。デジタル化は以前から進められてきたものであるが、コロナ禍はデジタル技術の活用を人々に半ば強いることとなり、急速に普及している。これほどまでに急激な社会への実装はコロナ禍無しには成し得なかったであろう。あらゆる交流や取引のデジタル化が進むなか、日本はこの分野で競争力を持つことを目指している。

政府はデジタル化とともに脱炭素を、コロナ禍からの経済回復とともに長期的な経済成長の原動力と位置付けている。2050 年カーボンニュートラル実現に向けた道筋は議論の過程にあるが、目標達成のハードルは高く、産業構造やエネルギー需給構造の改革は過渡期に産業界や人々に痛みをもたらすことも考えられる。そのため、コロナ禍というショックがなければ、政府はこの大きな決断をこれほど短期間のうちに成し得なかったかもしれない。

2）ドイツ

ドイツでは、コロナ禍は政府の財政政策に重要な影響を与えるのではないかと見られている。ドイツは従来、景気刺激などを目的とした財政支出に比較的寛容であったが、金融危機後の 2009 年に財政政策を転換し、連邦政府の財政は原則バランスさせ、構造的な財政赤字を GDP の 0.35%以内に抑えるという方針を定めた。これは、小さな政府を目指すネオリ

ベラル的な与党の方針とも合致した。

コロナ禍では、緊急避難的な措置としてこの財政規律を破ることが行われた。ドイツ国内では、コロナ禍による巨額の経済対策が財政政策の転換点となるのか、また生じた債務の解消に向けた増税を行うのか、といった議論が行われている。緊縮型の財政は、財政出動があれば誘発されるはずであった民間投資をなくし、またそのことが政府の産業政策を弱くし、結果として産業の活力やイノベーションやグリーン産業の可能性を縮小する結果になっているのではないか、というものである。逆にコロナ禍による巨額の財政支出は民間投資を誘発し、過剰貯蓄を緩和するものとなる。

気候変動という困難な課題と対峙するにあたって、より積極的な政府の関与を求めようとする認識の変化もある。また、コロナ禍を受けた半強制的なものとはいえ、社会の変化を目の当たりにした政府は、デジタル化の加速や医療システムの強化、リモートワークの支援、交通政策における優先の変化など、政府支出の優先順位に変化が生じると考えられる。

2.3.4　日独の比較分析

1）新型コロナウィルスの感染状況の違い

原因は定かでないが、日本とドイツでは感染者および死亡者の数が大きく異なる。コロナ禍のひっ迫度は政策や人々の認知に影響を与えると考えられるため、日独の比較を行うに際しては、背景にある事実として理解をしておく必要がある。

2）経済全般への影響

OECD によると、日本とドイツの 2020 年の GDP 成長率は、それぞれ-4.25%と-5.5%のマイナスとなった。その結果、日本とドイツはともにエネルギー消費量と CO2 排出量が減少した。日本とドイツは 2021 年以降に経済の回復が見込まれているが、両国とも世界経済に強く組み込まれていることから他国の影響から無縁ではいられない。この意味から、途上国のコロナ対策を支援することは単に倫理の問題ではなく、両国経済の問題でもある。

コロナ禍の長期的な影響は多様かつ未だ不透明な部分が多い。短期的に経済のあらゆる分野で負の影響を与えたことは確かであるが、構造的な変化がどの程度誘引、定着するかは明らかでない。また、国際的な産業の分業体制に生じ得る変化と、結果としてエネルギー消費と CO2 排出に及ぼす影響も未知数である。

日独はともに自動車産業で強みを有するが、コロナ禍によってダメージを受けた。またモビリティの在り方そのものが変質する可能性も示唆している。例えばコロナ禍によってエネルギー・環境的にはより好ましい公共交通の運営が難しくなっており、持続可能なモビリティサービスの模索が必要になっている。

3）生活スタイルや個別分野への影響

コロナ禍に起因する変化の中には日独で共通のものがある。移動量が公共交通や空運を

中心に減少し、人々は自動車や自転車、徒歩を好むようになった。コミュニケーションツールがデジタル化し、生活や労働、余暇、教育などあらゆる場面で情報通信技術が利用されるようになった。ドイツでは技術に対する受容性が高まった。日本では、永く模索されてきた労働生産性の向上や行政手続きの効率化に貢献する可能性がある。

ただし、デジタル化がもたらすネットの便益は明らかでない。ドイツでは、リアルな経済活動の減少がもたらす国民の経済格差の拡大やエネルギー貧困問題、持続的かつ公平なモビリティサービスを以下に提供するか、という点に関する議論が高まっている。

4）経済対策

IEA によると、「各国政府はより良いエネルギーの未来を形作るための、生涯に一度の機会を手にしている」。この視点にたったとき、日本とドイツの経済対策は景気刺激策として効果的であることはもとより、気候問題と対するうえで十分なものとなっていることが求められる。世界は模範となる例を必要としており、日本とドイツは協力してこれを示していくことができる。

経済対策のグリーン比率を金額で比較することに意味はなく、エネルギー転換に対する実際の効果を推し量るべきである。

- 経済対策による投資はどの程度持続可能な構造への転換や脱炭素目標の達成に貢献するか？
- デジタル化はネットで脱炭素にどの程度貢献するのか？
- 社会や行動の変容はどの程度定着するのか？
- 政策のスタイルはどのように変化するのか？（小さな政府から大きな政府へ？）

2.4.4　まとめ

世界ではワクチンの接種が段階的に始まり、新型コロナウィルスの封じ込めに向けた光が見えつつある。しかしコロナ禍からの回復過程は世界で一様ではないと考えられ、日本とドイツはともに、今後数年間に渡って大きな経済的影響を受け続ける可能性がある。コロナ禍の完全な収束は 2021 年中には見込めないかもしれないが、社会の変化は新たな可能性も同時に提示しており、それらを活用することもできる。すなわち、コロナ禍は日本とドイツに脅威と機会を同時に与えているといえる。そのため今後応えるべき最大の問いは、コロナ禍を 2050 年のカーボンニュートラル実現に向けた大きな変革の機会とするのか、持続不可能な従来の成長パターンに戻るのか、である。

この視点に立てば、今後為すべきことは、2050 年カーボンニュートラル目標の実現向けてコロナ禍がどの分野や技術、行動変化に正の影響を及ぼすかを見定め、それを維持・強化するための措置を講じることである。そして逆に、コロナ禍が 2050 年カーボンニュートラル目標の実現にもたらす負の影響を阻止・緩和するための仕組みも構築していかなければならない。

また、こうした新しい取り組みはベストプラクティスを共有することで互いの変革をより円滑かつ迅速にすることが期待できる。この点で、日独評議会は 4 年間に渡る活動実績をもとに強固な信頼関係を築いており、こうした共同研究を推進するのに最適な枠組みの一つといえる。

第 3 章　日本のエネルギー政策への提言

3.1　日独評議会での議論・検討の結果を踏まえた提言

ここでは先ず、3 つの研究を通じてえられた示唆を整理、検討する。

3.1.1　デジタル化とエネルギー変革 AI や分散型エネルギーのビックデータなどデジタル技術を活用した送電運用の最適化

日本については唯一の事例と考えられる実現可能性調査の結果が得られていない現時点では、事例考察からの政策的インプリケーションの導出は時期尚早と考えられる。しかしながら、ドイツの事例から得られる示唆として以下が考えられる。現状の実現可能性調査で検討されている DER 活用プラットフォームに関する検討は主として技術的側面に焦点が当たっていると見られるが、ドイツの事例に対する考察は、技術的側面と並行して経済的な側面の検討を深めておくことの重要性を示唆している。ここでの経済的側面とは、例えば、DER の活用を促すための価格シグナルの形成とそれを実現するための地域柔軟性市場の形成である。技術的側面が満たされても、経済的な側面の確立が伴わない限り、検討されているビジネスモデルが実現することは困難であるという至極当然の帰結がドイツの事例から明らかとなっている。同様に、ドイツの事例から、DER の柔軟性ポテンシャルを引き出すには電力システムや市場に対する規制緩和が不可欠であることも明らかとなっており、これも日本にも同様に適用できると考えられる。

次に、ドイツの事例考察から導出された政策的インプリケーションは以下の通りである。

- 配電系統の最適化のために DER の柔軟性を活用することは技術的には可能であるが、現状のドイツでは DER の柔軟性が十分に活用できる環境が整備されていないため、そうした環境（regulatory environment）を政策的あるいは規制的に形成することが必要である。その上で、DER の柔軟性を当日市場での価格シグナルを通じて提供するのか、その場合、DER 所有者による制御なのか、配電事業者による制御なのか、あるいは、地域柔軟性市場を通じて提供するのかについて制度設計にあたって決定しておく必要がある。要するに、DER の柔軟性を（技術的な側面に加えて）経済的に引き出す手段は何なのかについて目的を踏まえた検討が必要とされる。ドイツの SINTEG プログラムにおいてもこれらの点についての検討は不十分であり、今回調査対象としたプロジェクトの多くも実証事業にとどまり商用化まで進んでいない。
- 地域柔軟性市場を実現するためには、柔軟性の潜在的な供給者が発電・消費プラントや蓄電池を所有することや商用ベースで送配電事業者に地域柔軟性を提供できるように、既存の規制の枠組みを緩和・改変してゆく必要がある。例えば、現状のドイツの規制においては地域柔軟性市場の設立・運用は認められていない。

- DER を活用して最適化するべき配電系統の範囲を検討する必要がある。例えば、非常に小さな区画、都市中心部、周辺エリアも含んだ都市全体、あるいは DSO の配電エリア全体など最適化すべき範囲の決定因子はまだ不明確なままである。また、一般的な議論として、単独の配電系統内で、または配電系統の一部分だけで需給バランスを維持することは本当に可能なのか、あるいは、配電系統のバランスを維持するために必要な送電系統との協調のレベルなどは依然として明確になっていない。既存規制の緩和・改変はこれらのテーマに関する今後の洞察結果に基づいて行われるべきである。
- また、SINTEG プログラムの C/Sells プロジェクトにおいては、今後必要とされる具体的な取り組み提案として以下が挙げられている。
  - 規制緩和によって小規模な DER の市場へのアクセスを簡素化し、新たな活動機会の提供の創出（例えば、近隣コミュニティ内、自主的な自家消費発電事業者、再エネコミュニティの中でのエネルギー取引、さらには柔軟性プラットフォームへの自主的参加による系統混雑緩和への利用など）。
  - 系統運用事業者や柔軟性提供者が系統運用への柔軟性活用に対して追加的コストを負担するのではなく、むしろ逆に系統運用への柔軟性活用に対してインセンティブを付与できるような合理的な賦課金、料金、手数料体系な設計。
  - 地域全体の柔軟性の可能性と実現可能性の分析の実施、およびドイツのすべての DSO を最終的にカバーするためロードマップの策定。
  - DER 接続のインターフェイスやプロセスの標準化、および標準化されたスマートグリッド・インターフェイスのラベルの開発。DER の柔軟性を高めるために、リレーを使わずに制御できるデジタルインターフェースを定義し、ゲートウェイを安全な通信・制御コンポーネントへと改変。

3.1.2　CCUS や水素を活用したエネルギー多消費産業の脱炭素化

産業部門の脱炭素化はドイツおよび日本にとって共通の課題である。両国は、産業部門における水素利用を推進する政策枠組みを策定し、水素のサプライチェーンに関する RD&D を促すための支援を提供している。ドイツは水素の直接利用に関する大規模な RD&D 事業で先行している。一方、日本では、産業部門の大規模な水素利用の実証事業は限定的で、地方自治体における輸送・民生部門における水素利用に関する小規模事業が中心となっている。両国にとって、水素の生産および（船舶による）輸入コストは主要な課題となっている。消費者への水素配送に関して、ドイツは、ガスへの水素混合は、実現する前に様々な課題をクリアする必要があるが、既存のインフラを活用する機会と捉えている。しかし、日本は、ガスインフラがドイツ程拡充されていない、既存のガスインフラや技術に対する水素混合による影響の詳細な調査や長期的な戦略が欠如しているため、水素のガスへの混合はあまり議論されていない。

ドイツと日本は、CCS に関して、社会的受容性（特にドイツ）や限定的な可能性といった類似の障壁に直面している。そのため、両国は CCU の検討に動いており、特に日本はカーボンリサイクル技術を注視している。しかし、両国において、CCU のライフサイクルアセスメント、CCU を使った製品の市場性、CO2 インフラの開発といった課題も認識されている。

このような課題を受けて、日本では、まず国内外水素のコスト削減に向けた技術開発を継続的に進めるとともに水素利用に対する優遇措置の検討が必要である。特に、国際的な水素サプライチェーン確立のために、世界で容認される低炭素水素基準・証書の整備も欠かせない。

また、水素を産業部門へ供給するためには、追加的なコストを最小限としつつ既存の都市ガスインフラへどの程度水素を混合できるかの詳細な調査から着手しなければならないと同時に、新規水素インフラ構築の検討も課題である。

CCUS では、まずはライフサイクル CO2 分析に基づく個別技術の評価が必須となる。促進策としては、政府による RD&D への継続的な支援とともに、民間部門だけでは困難なインフラ整備に関する明確な政策方針が投資促進に資すると考えられる。また、産業部門の競争力を保ちつつ、CCUS の経済性を改善するようなカーボンプライシング制度の構築が CCUS の技術開発を加速させると考えられる。

3.1.3　新型コロナウィルス後のエネルギー／気候政策

１）2050 年炭素中立実現に向けた好機としてのコロナ禍

新型コロナウィルスの蔓延は災厄であり、現在も経済に大きなダメージを与えていることは疑いようのない事実である。日独政府はともに、先ずは医療の支援やダメージを受けた個人および企業の救済に乗り出したが、その後景気刺激策の一部に、産業構造を改革、強化し、また 2050 年カーボンニュートラルを実現するという未来に向けた投資を含めるようになった。日本では 2020 年 12 月の「国民の命と暮らしを守る安心と希望のための総合経済対策」が、ドイツでは 2020 年 6 月の「Recovery Program」が該当する。

評議会では、コロナ禍からの回復について Response、Recovery、Redesign の 3 段階に分けて考えるというコンセプトが議論された。Response の段階においても、将来の社会や経済の Redesign を考えなければならないというものである。日独が講じている経済対策はまさにこのコンセプトに沿ったものであり、単に被害を救済するのみならず、将来達成すべき目標に沿った資金の供給を企図している。前述のコンセプトに倣えば Response、Recovery、Redesign の 3 段階でバランスが取れ、コロナ禍の災いを転じて福となすための政策といえる。

このように日本とドイツでは類似のコンセプトのもとで景気刺激策を講じているが、具

体的な支援対象や執行方法はそれぞれの国情を反映したものとなる。ドイツは電気自動車や充電設備の普及拡大や従量車の非化石燃料化、鉄道など公共交通の維持・強化など、運輸部門の脱炭素化に重きを置いた支援メニューを提示している。これらの中には日本にとって参考となる手法が含まれているかもしれない。

一方の日本は、運輸部門はもとより建物や再エネの普及、産業部門、バイオマス資源の地産地消など、より網羅的である。また、海外での事業や国際協力を挙げている点はドイツにない特徴といえる。ただし実際には、ドイツも低・脱炭素技術の海外での展開を積極的に行っている。日独の企業が、なかでも一般的に日本の地の利が薄いと考えられるアフリカ大陸などの第三国において、機能を相互補完する事業を行うことができれば理想的であろう。

２）行動変容の見極め

コロナ禍の下で人々の生活様式や働き方は大きく変化した。全体として物理的な移動が減少し、インターネットを利用したコミュニケーションや取引が増えた。物理的な移動の減少は特に石油需要を減らす一方、インターネットの利用が増えることで電力需要が増加する。2020 年 12 月までの実績をみると、石油需要の減少は電力需要の増加を上回っており、二酸化炭素消費量も減少したと考えられる。これはエネルギー・気候政策の観点からは好ましい変化である一方、景気回復の過程で需要のリバウンドが懸念される。

人々の行動変容が今後どの程度定着していくのかを見通すことは簡単でなく、また期待する方向に誘導することも容易でない。しかし、脱炭素を目指すうえでは、供給側のみならず需要側の変化を促すことも手段の一つとなる。例えば、税や道路への課金などによって自動車による移動コストを高めるたり、あるいは新しいコミュニケーション／ビジネススタイルのメリットを広報することによって人々の移動量を抑制することができれば、2050 年カーボンニュートラル目標の達成に一歩近づくことができる。この分野の知見はドイツでも十分に積みあがっておらず、共同で手法や効果を検討、分析する意義がある。

3.2　ドイツの産業政策と日本のエネルギー産業の競争力への示唆

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

3.2.1　ドイツの産業政策

ドイツの産業が引き続き世界の中で競争力を維持し続けるためには、イノベーションの発揮に適したビジネス環境と熟練労働者の供給の維持が必要としている。連邦経済・エネルギー省（BMWi）は今後のドイツ産業でカギとなる分野と技術を特定しているが[1]、機械・プ

[1] BMWi, https://www.bmwi.de/Redaktion/DE/Textsammlungen/Industrie/leitmaerkte-mit-

ラントエンジニアリング技術、電子工学、生産技術、材料技術、バイオ・ナノテク、ヘルスケア・医療技術、モビリティ・物流、ICT などと並んで、エネルギー・環境技術を挙げている。特に ICT 技術については、あらゆる分野でより複雑な製品やサービスを生み出すことに貢献するとしている。エネルギー・環境およびモビリティ分野で重視している技術を以下に示す。

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

気候変動問題と関係では、産業は気候変動や省エネ・省資源、再エネ拡大における経済への影響という点で重要な役割を果たすとしている。環境保護は産業にとってコストであると同時に、新たなビジネス機会ともなるためである。BMWi は、ドイツ産業のなかでは機械やプラント、計測設備、電気設備に係る産業はグリーン技術の輸出によって、相手国の環境問題解決に重要な貢献を成してきたとする。また、ドイツ政府は環境保護と気候変動の緩和に向けた努力を産業にも求めると同時に、クリーンな生産プロセルの開発の支援を行う。

政策のスタンスでは、市場を重視した技術中立なものを志向している。経済効率性への配慮が必要であり、そのためには企業間の競争を促す必要があるためである。また、科学的な発見をすばやく商業的な技術や製品、サービスへと展開するイノベーションを企業に促すことを目的とした「High-tech Strategy」を 2014 年に定めた。具体的には、産学間のコミュニケーションや連係を強化し、また中小企業や研究グループによる国際貢献を含む活動を支援する[2]。

原材料とエネルギーはあらゆる産業にとって不可欠な物資であり、この供給について次のような方針を定めている。原材料については、供給の輸入依存度が高いため、安定供給を確保すると同時に、効率的な利用や再利用を促す。また、化石資源の資料が次第に制限させ

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zukunftspotential.html, 2021 年 3 月アクセス
[2] BMWi, https://www.bmwi.de/Redaktion/EN/Artikel/Technology/high-tech-strategy-for-germany.html, 2021 年 3 月アクセス

れていくため、代替としてバイオマス資源にも注目している。

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

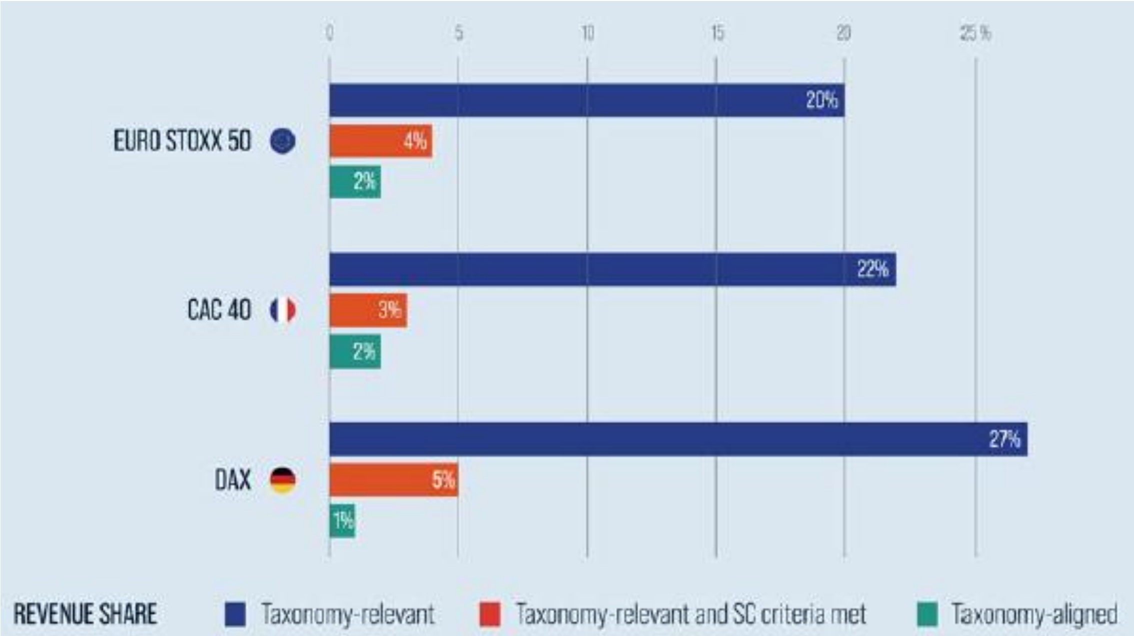
ドイツの産業競争力強化に向けて、2015 年に BMWi を含む 17 の組織・団体が参加する Alliance for the Future of Industry（未来の産業に向けた同盟）が組織された。デジタル化やプラットフォームビジネス、グローバル化、気候変動問題、他国との競争などドイツ産業界を取り巻く環境が大きく変化するなか、同盟は多様なステークホルダー間の対話と議論を通じた、政策形成に対するインプットの場として機能している。また同盟は、カンファレンスを主催するほか、幾つかのモデル地域で同様な対話の場を構築することで地方の産業と BMWi を結びつける役割も担っている。

3.2.2　企業の低・脱炭素事業の現状

ドイツは温室効果ガスの排出削減で野心的な取り組みをしてきたことで知られているが、実体経済を担う企業は必ずしもその政策に追従できている訳ではないあ。

2020 年にドイツの連邦環境・自然保護・原子力保安省（BMU）が行った調査[3]は、興味深い結果を示している。調査は欧州（EURO STOXX 50）、ドイツ（DAX）及びフランス（CAC 40）の主要株式指標の採用銘柄企業のうち 75 社を対象に行ったもので、それら企業の活動が、欧州タクソノミー案がグリーンと定義する分野とどの程度一致しているかを、売上高を基準に評価している。調査によると、タクソノミー案のグリーン定義と完全に一致する事業の売上げは、EURO STOXX 50 企業の合計売上の 2%、DAX 企業の 1%、CAC40 企業の 2%にしか過ぎない。「関連する分野」に枠を広げると率は上がるが、それぞれ順に 20%、22%、27%と、2 割から 3 割にしかならない。企業別には、対象とした企業数の 77%は、タクソノミー案のグリーン定義と完全に一致する売上げは 1%以下である。すなわち、大部分の企業にとって、グリーンビジネスは平均的には売上の 1%を占めるに過ぎないマイナーな事業であり、収益の大部分は非グリーン事業が生み出していることを意味する。

[3] BMU, European Sustainable Finance Survey 2020



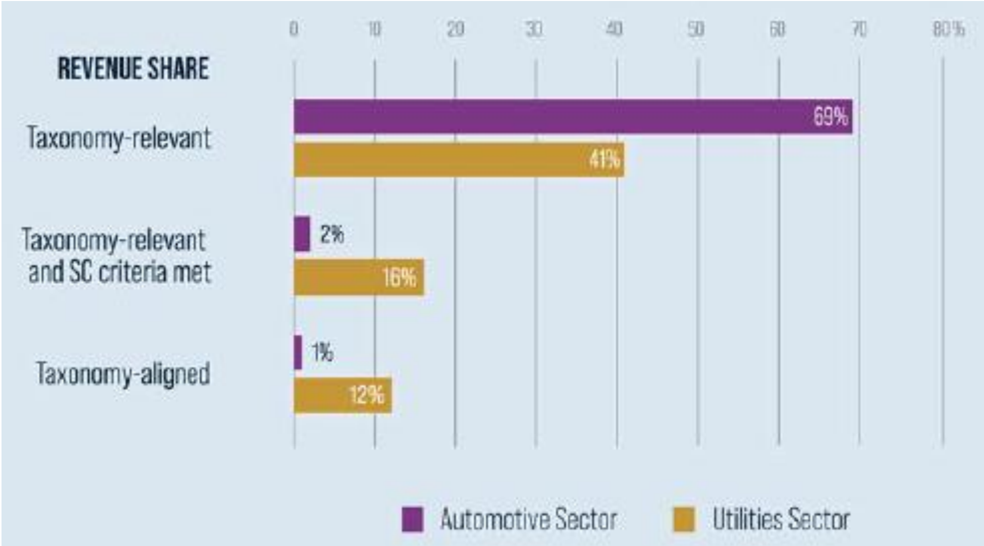
SC = criteria met: 一定の CO2 排出基準未満の事業活動。

出所：BMU, European Sustainable Finance Survey 2020

図 3-1　タクソノミー案の定義に適合した売上高の率

また同調査では、ドイツの成績があまりよくない要因として、対象企業に自動車を含む製造業が多く含まれていることを指摘している。ユーティリティ企業（電力・ガス供給業）と自動車製造業を比較すると、ユーティリティ企業の方がタクソノミーと合致する売り上げの率が高いことが分かる。差異の背景には、特に電力では再生可能エネルギーを容易に利用できることがあると考えられる。この結果は、分野にもよるが、供給側よりも需要側の脱炭素の方が難易度が高いであろうことを示唆している。

調査結果は改めて、現在の経済は炭素排出の多い活動のもとで動いているということを認識させる。逆に、グリーン政策で野心的な目標と政策を矢継ぎ早に投じ、また社会の多くが脱炭素化に向けて積極的に動こうとしているように見えるドイツにおいても、実態経済の変化は未だ端緒についたばかりであることが分かる。



SC = criteria met: 一定の CO2 排出基準未満の事業活動。

出所：BMU, European Sustainable Finance Survey 2020

図 3-2　ユーティリティ企業と自動車製造業のタクソノミー案適合売上の比較

3.2.3　日本のエネルギー産業の競争力強化に向けて

国際的な産業競争力を強化するためにイノベーションが必要であることは、日本のエネルギー産業も同じである。日本企業が優位性を持つ技術は多々あるだろうが、優位性は未来永劫保証されている訳ではない。また時代が必要とする製品やサービスは移り変わるものであり、現在はニーズのある技術もいずれ不要となる時期が来るかもしれない。このことは、例えば音楽の視聴方法の歴史をみれば明らかである。音楽の記録媒体としてのレコードはその後カセットテープや CD に取って代わられ、音楽配信サービスが普及した現在は、目に見える記録媒体はほぼ取り扱わなくなった。そしてこの変化は、記録媒体を製造、販売する産業に大きな影響を与えた。エネルギー産業も然りで、今後技術や規制の変化、消費者ニーズの変化に合わせて自身を変えていくことができなければ、縮小するパイのなかで衰退していくしかないだろう。

では、今後需要が高まる技術やサービスは何であろうか。個別に技術やサービスを予測することは不可能であるが、エネルギー・環境政策の大きな潮流を見れば明らかなこともある。先進国のみならず一部の途上国も、今世紀半ばまでにカーボンニュートラルを目指すことを宣言している。実現可能性の議論はさておき、低・脱炭素に貢献する技術やサービスに対するニーズが今後ますます高まる蓋然性は高いと考えられる。そのため日本のエネルギー産業の競争力強化に向けては、この分野でのイノベーションを促すことが求められる。

イノベーションの促進に向けては、次の施策が考えられる。

① 学術的な知見や発見の商業技術やサービスへの展開を促す仕組み
産学間の情報と人材の交流を密にすることで、商業的イノベーションの芽を見出す可能性が高まることを期待できる。

② 商業的なニーズを学術研究に反映するための仕組み
商業的なニーズをもとに学術研究を行えば、より効率的に学術研究を商業的なイノベーションに結び付けることができる。ただし商業化を意識しない基礎研究も重要であり、それを否定するものではない。

③ 企業間の自由な競争と技術中立性の保証
自由な競争は挑戦や創意工夫の原動力である、コスト削減でも効果を発揮する。どの技術が花開くかを正確に予見することはできず、イノベーションに係る発想の幅を広げるためにも技術中立性に対する配慮は重要である。

④ 国内で十分に実証を行うことができる環境の提供
日本の競争力を高めるためには、国内で十分に実証を行うことができる環境を整え、国内で新しい知見を蓄積していくことが必要である。

⑤ 「魔の川」と「死の谷」を乗り越えるための支援[4]
有望な技術ではあるものの企業が商業化に向けたリスクを負担できない場合は、研究から開発へ、開発から事業化へと展開していくことを政府が支援することが求められる。

⑥ 新技術・サービスに関する外交
海外の市場開拓では、民間企業よりも政府によるアクセスが有効な部分がある。政府は、相手国政府に日本の技術やサービスの有用性を認知させることで、企業による市場開拓を支援することができる。

エネルギー設備は投資サイクルが長く、数年など短期間のうちに全てが入れ替わってしまうことはない。また、国によって特に経済的な受容性が異なるため、この意味でも技術に対するニーズの変化も段階を経たものとなることが考えられる。他方でイノベーションも短期間では成し得ず、そのために将来を見越した行動が必要である。ドイツは日本にとって

[4] 技術を基にしたイノベーションを実現するために、各段階で乗り越えなければならない障壁を指す。「魔の川」は、研究ステージと製品化に向けた開発ステージの間に存在する障壁。「死の谷」は、開発ステージと事業化ステージの間に存在する障壁。（日本能率協会コンサルティング）

国際市場における手強い競争相手であるが、であるからこそ彼の国から学べることもあるだろう。日独エネルギー変革評議会の枠組みは、この点で効果的に機能することができる。

付録１．日独エネルギー変革評議会の記録

日独エネルギー変革評議会（その１）
2020 年 6 月 22 日（火）

Welcome and brief introduction

- コロナ禍は石油需要の減少やデジタル技術に対する期待の高まりなど、エネルギーにも変化をもたらしている。現在見られる変化は更に継続、加速することも考えられ、国際情勢を注視する必要がある。学術的な見地に基づくこれまでの日独評議会の活動は有益である。日独には水素に係るイノベーションなど協力強化の可能性がある。エネルギー転換の実現に向けてはあらゆる選択肢を活用していく必要がある。日独評議会による有意義な成果に期待。
- 現在われわれはコロナ禍からの回復に注力しているが、エネルギー転換を加速する機会でもある。コロナウィルスとは異なり、エネルギー・環境問題への対応策は明らかである。ドイツの経済回復パッケージでは、新しいモビリティや水素など、将来の技術に投資することを決めた。またコロナ禍は、国際協調や科学に基づく意思決定の重要性を気づかせた。GJETC は我々が必要とする協調のモデルであり、両国のエネルギー転換に貢献することを期待。

GJETC report 2020

- デジタル化について、P2P は未熟で、今後どのような影響をもたらすか未知な部分が多い。過去何年にも渡って両国はマイクログリッドの研究を進めてきたが、現在に至るまでエネルギーシステムに大きな変化はみられない。VPP はマイクログリッドの発展形だろうが、これが最終形ではない。VPP は従来の電力会社と同じビジネスを作り出すものであるが、これに対して P2P は全く異なるシステムを作り出すかもしれない。制度を複雑化することなく、新たな技術を入れていくことを考えなければならない。
- 日本のコロナ禍経済対策について、エネルギー・気候関連にはどの程度の資金が供給されるのか。
    - エネルギー・環境関連投資は一般予算のなかで扱われている。コロナ禍の経済対策は短期的に企業活動や失業の支援を行うものであり、現在の予算にはエネルギー・環境関連は入っていない。秋に追加的な予算措置がされるかもしれない。
- ドイツでは建物の最低効率基準に関する新法が今年中に通過する見込み。
- コロナ禍の経済対策パッケージは、景気回復だけではなく、改革によって国をもっと持続可能な構造へと変えていくものとすべき。
- 景気対策は額の大きさに目が向きがちであるが、資金供給の方法にも注目すべき。資金

供給はより早く、より効果的なものとすべきであり、炭素価格などの方法によって資金を動かしていくことが必要ではないか。

- 炭素価格は非常に興味深いが、世界の全ての国が同時に導入しないと、欧州は競争力を失うことになる。

Integrating the Fight against the Coronavirus Crisis and Climate Change

- 「グリーン回復」の考え方に賛同。経済回復のみならず、気候変動や SDG 投資とも整合のとれた資金供給が必要。社会経済、技術の再構築が必要。社会の構造変化が重要であり、レジリエントかつ持続可能な地域社会を作らなければならない。
- ドイツでは FIT 賦課金の引き下げにも経済対策資金が使われる見込み。(8 セント以上となるところを 6.3 セント/kWh に抑制)
- 水素や公共交通機関の料金抑制にも支出される。
- 日独評議会のようなグループが声を一つにして発信することが重要。コロナ後の経済パッケージをグリーンディールに向けて動かすために何をすべきか考えなければならない。
- OECD が予測するようにコロナの経済影響が今後 2 年続くとすれば、人々は雇用など家計に直結する問題が最大の関心ごととならざるを得ない。この意味から、先ずは経済回復を優先させるべきではないか。グリーンニューディールを、人々が関心を寄せるもの（＝家計の改善に寄与するもの）としなければならない。省エネは好例だろう。再エネのコストを更に引き下げることが必要。

Retrospect and further cooperation

- 引き続き日独協力に期待。水素はもちろん、引き続き省エネやグリーン消費なども興味深いテーマ。
- 日本はデジタル化に強い関心を持っており、独から学び得る点は多い。カーボンリサイクリングは産業部門の脱炭素化で重要な要素。

Closing

- 日独評議会での議論は、当初は激しい部分もあったが、現在は相互理解が進み順調。本日の議論の感謝し、新しい様式の下での協力を継続することを期待。
- 日独は異なる点があるものの、共通の課題も多く抱えているおり、日独評議会における議論をまさにロールモデルといえる。

以上

日独エネルギー変革評議会（その２）
2020 年 9 月 25 日

Welcome and brief introduction

- 世界では covid-19 を含め情勢が大きく変化。日独では 2018 年から日独政府間の協力が強化された。日独はともに水素戦略を進めているが、課題解決に向けて様々な取り組みを進める必要がある。日独評議会の今年の研究テーマであるデジタル化とカーボンリサイクリングはともに非常に重要。有益な議論を期待。
- 日独評議会は日独パートナーシップの貴重な要素の一つ。CO2 排出量の削減は単に CO2 削減だけでなく、持続可能な発展のフレームワークであり、また新しい産業政策である。目標設定は始まりであり、様々な施策を展開する必要がある。また全てのステークホルダーの力を結集する必要がある。この意味から日独評議会に期待。

Digital application to optimize distribution/transmission grid operation

- デジタル化と Covid-19 の関係に大きな関心。生活様式の変化が都市構造にどのように影響するのか、デジタル化はどう影響するのか。
  - デジタル化研究では分散型のエネルギーシステムを扱う。Covid-19 は分散化をもたらすため、分散型システムと親和性が高いと理解。
  - 全てがリモートになる訳ではなく、将来どうなるかは不透明。慎重に分析すべき。
  - 決断を出すのが時期尚早であるのはその通り。ただ、議論をしておくべき。
- 50Hz（ドイツの送電会社）は、2030 年に 100%VRE を可能にするという目標を立てている。是非彼らにインタビューをしてはどうか。独側では、Transnet BW の系統でメルセデスと協力して PV と自動車ビッグデータ収集の活用を研究しているので参考になるだろう。
- 発電はさらに分散化していく。
  - 発電がさらに分散していくのはその通り。そのためデジタル技術の重要性は更に増す。一方デジタル技術も更に進化するため、可能性は大きい。
- 統合コストの論点が重要。システムコストの変化を分析することは出来るか？
  - デジタル技術活用のメリットはコスト削減。
  - システムコストの評価はドイツでも議論の最中。ドイツでは、電池コストの低下から、水素は需給調整技術というよりも、最終消費としての用途が重視されるようになっている。
- 電池の多くは中国製でコストも低下しているが、サプライチェーンの問題があると思慮。欧州はバッテリーの供給内製化（脱中国）を志向しているが（＝コストアップではないのか？）、それでも電池コストは低下するのか？
  - ベルリンでは次世代電池の開発に向けたテスラの新工場が建設中。電池の第一ウ

ェーブは中国が席巻したが、第二ウェーブでは欧州が主役になると期待。

- ミュンスターでも電池開発の拠点がある。デジタル化調査では、規制の問題を分析するのか？
  - ➢ 規制問題の重要性は認識。
  - ➢ 別の事業で、デジタル技術を活用した分散型エネルギーの統合では柔軟性市場の活用など、5 つのモデルケースの分析を実施中。これらの成果も活用したい。

Carbon-recycling and other technologies to decarbonize energy intensive industries

- 脱石炭は産業、特に鉄鋼、化学などに強い圧力を与えている。重工業が集積した NRW 州でも活発に議論が行われており、4R は重要な視点。
- CCS は地質構造に依存することに注意。
- ドイツでは CCU は鉄鋼産業が推進してきたが近年は関心を失いつつあり、代わり化学産業が関心を示している。都市ガスでは、ブレンディングから 100%水素に議論が移りつつある。また、水素の用途は産業と貨物車などが中心になると見られているが、水素転換は漸増的な変化ではなくステップ的な変化となるのではないか。ステップ的な変化の場合、短期間内に巨大な初期投資と供給量が必要になり、これをどのように実現するかを考えなければならない。ドイツでは 5 つの水素開発目標を検討中（電解コストの削減、電解プラントの稼働率向上、輸送コストの削減、など）。
- ドイツの産業では大気からの二酸化炭素直接回収（DAC）に対する関心が高まっている。
  - ➢ DAC は一部で商業化が近いと聞いている。
  - ➢ DAC が消費するエネルギーの 8 割は熱。熱をゼロエミエネルギーで作ることが出来れば意味がある。
- 多くの CO2 排出はアジア途上国に由来する。アジアの途上国でこそ CCS の展開が期待される。
- 地震の多い日本では CCS よりも CCU が良いのではないか。二次エネルギーの CO2 排出量はどのように評価すればよいのか。
  - ➢ 合成燃料の燃焼では CO2 は気にしなくてよい。
- カーボンリサイクリングの魅力は何か。
  - ➢ カーボンリサイクリングは様々な原材料へと転換することが可能。化石燃料を大量に消費している分野でこそ生きる技術。

Energy/Climate policy in the post COVID-19 era

- 現在は 2℃目標との間に大きなギャップがある。Covid-19 はこのギャップを埋める機会となるかもしれない。研究成果を上手く政策に結び付ける必要がある。
  - ➢ 現時点ではどのような政策提言となるか分からない。個人的にはコロナ対策と気

候対策を統合的に扱うことはコストではなく、最終的には大きな利益になると思慮。政策に反映するためには、経済合理的な選択となる必要がある。

- この調査の論点は全ての国に共通の問題。一方、中国（石炭火力の建設）やインド（国内炭開発）ではコロナ対策から気候変動とは逆の動きが見られる。このように、Covid-19 は途上国では、経済の現実と気候変動対策のギャップを広げる方向に作用している。この研究はこうした現状の改善に貢献することを期待。
  - ➢ 途上国では再エネコストの著しい低下も見られており、経済対策と気候対策の二兎を追う win-win の政策に展開できるのではないか。
- 技術だけではなく行動変容や政策の変化も分析するのは有意義。
- Covid-19 後の経済回復ではグリーン回復というよりも持続可能な回復であるべき。
  - ➢ 持続可能な回復に賛成。

<u>Expression of thanks and closing remarks by the Co-Chairs</u>

- 有益な議論に対する感謝が述べられ、閉会。

以上

日独エネルギー変革評議会（その３）
2021 年 3 月 12 日

Welcome and brief introduction

- Covid-19 への対策が進みつつあるが、依然として大きな影響下にある。コロナ対策のために我々は将来世代から金を借りており、無駄にしてはならない。グリーン水素や行動変容などの策が講じている。ドイツは脱石炭を決めたが、ある炭田はグリー水素製造拠点に転換することが決まった。またドイツでは炭素価格を導入したが、日本にも是非検討してもらいたい。将来を見据えた活発な議論を期待。
- コロナ禍から次第に回復しつつあるが、貿易や生活様式など我々に大きな影響を及ぼしており、引き続き慎重に見極める必要がある。日本では昨年菅首相が 2050 年カーボンニュートラル目標を発表したが、多くの政治家と産業界がこれを支持している。これまでとは違う新しい技術やビジネスモデルを見出さなければならない。またグリーン成長戦略を策定した。日本とドイツはともに重工業を中心とした産業構造であり、協力の余地は多くある。日独評議会は 2016 年以来様々な成果を出してきたが、今年も有意義な成果を期待。

- 日独双方の政策担当者の同席に感謝。また、両国政府の支援に感謝。2050 年炭素中立に向け、学術的な見地から貢献したい。
- 日独両政府の支援に感謝。これまで多様な分析と提言を行ってきたが、炭素中立の実現に向けた有益な成果を期待している。

Digital application to optimize distribution/transmission grid operation

- 日独の経験は相互補完的。価格シグナルによる家庭のデマンドレスポンス（DR）に関するパイロット事業はあるか？
  - ➢ 家庭の DR は比較的古くから実証がされているが、多くの家庭は毎日価格を確認したがらない。自動的に最適な選択を行う仕組みが必要だが、得られる経済的利益が投資に比して小さいことが問題。電気温水器を使った調整はこれまでもやられている。ポテンシャルはあるが、実装には課題がある。産業の方がやり易いかもしれない。
- 制度的な枠組みの見直しが必要ということだが、経済的なインセンティブの必要性をどう考えているか？
  - ➢ 分散型エネルギー（DER）の管理は必要でデジタル技術は不可欠。
  - ➢ 技術的な実現可能性は高いが、一般家庭に設備を入れるには経済的インセンティブが必要。どのような方法でインセンティブを与えるかは議論の余地が大。
- デジタル技術は DER 統合のカギだが、高コストな貯蔵をなるべく利用しないで済むよ

うなエネルギーミックスを構築できるか？

- 現時点では明確な答えはない。選択肢は多くあるが、最適な組み合わせをどうやって見つけるかの答えはない。
- 熱に転換した貯蔵は安価な選択肢。電池も量産効果で価格が下がる可能性もある。地域によって需給バランスが異なるため、これを組み合わせることが出来れるかもしれない。

- ブロックチェーンなどを活用したスマートな契約の必要も高まると思慮。日本でこれらに関する取り組みはされているか。
  - 様々な取り組みがされている。

Carbon-recycling and other technologies to decarbonize energy intensive industries

- CCUS と水素について、ドイツでは鉄鋼業と重量車（heavy-duty-vehicle）と強く結びついており、これらの点で政治的な影響下にある。また政策的にはグリーン水素を強調しているが、2030 年に 60TWh と推計されている水素需要と電解容量（現状 15TWh）のギャップが大きく、ノルウェーからブルー水素 20TWh を輸入する計画がある。ブルー水素では CCS の貯蔵容量ではなく、年間注入量がボトルネック。それでもギャップはあり追加輸入が必要。既存ガス PL を水素用に転換することや、新規純水素 PL、船舶による輸入の可能性が議論されている。このとき、欧州市場でガス価格と競争可能な水準となるよう、輸送コストの低下が必須。
  アンモニアを化学や自動車燃料とする議論が行われている。北アフリカでブルーアンモニアや化学製品を製造し、それを輸入することの経済効果を議論している。
  水素の天然ガスへのブレンディングはもう議論されておらず、純水素に向かっている。
- 日本では比較的容易なアンモニアから始めようという議論がある。ただし発電におけるアンモニアの直接燃焼のみ。長期的にはアンモニアを水素に戻して利用する必要ある。

COVID-19 and the energy transition

- グリーンリカバリーや多様性の維持、コロナからの回復を 3R（response, recovery, redesign）のコンセプトで考えている。Response の段階でも Redesign を考えなければならない。
- コロナ禍は生活や財政など様々な側面で影響を及ぼしている。長期の視点でどのようなシステムを目指すべきかを考えなければならない。
- 日独では様々な協力が行われているが、デジタル化は需給両面で課題解決のカギとなると思慮。脱炭素化に向けて脱炭素エネルギーの投資、統合をどう進めるかが課題。また、既存インフラ、システムを如何にして脱炭素社会に適したものに転用していくかを考えなければならない。また、近年は水素に対する関心が急速に高まっていることに驚

いている。

- コロナ禍で輸送部門が特に大きな影響。一方、GHG 排出量の目標達成という点では良い面もあった。コロナ禍が引き起こす恒久的なシステムや行動の変容が炭素中立の実現にどのような結果をもたらすかを検討する必要がある。

Discussion for study topics, meetings, events

- COP26 のシナリオへの影響、NDC の引き上げなど重要な変化があるかもしれない。国際協力における日独協力、ガバナンスも興味深いテーマ。
- 長期シナリオの比較のなかで COP26 の影響を織り込めるかもしれない。国際協力については、議論中の日本の新しいエネルギー基本計画では国際協力の視点が入るとみられる。これも長期シナリオの比較の中で扱うことができるかもしれない。
- 削減コストの上昇から欧州では国境調整税を議論。重要だが時間のかかる議論。産業界と行政で見方も違っている。研究テーマとすることが適当か分からないが、少なくとも議論は出来るのではないか。
- 炭素価格の議論とともに扱えるのではないか。
- 産業の脱炭素は重要。我々の議論に市民を巻き込み、ライフスタイルを変えることを進めることも重要。脱炭素は技術だけでは実現できない。
- 2030 年目標の達成に向けては自由度が低く、利用可能な技術を当てはめるしかない。一方 2050 年は自由度が高い。そのため新鮮な視点で柔軟に議論することが必要。
  長期シナリオの比較は、究極的には市場と規制の議論。幾ら技術と行動変容を想定しても、市場と規制が適切に変化しないと実現しない。(目標実現に向けてどのような市場と規制が必要か?)
- 技術的選択肢はある程度分かっているので、実現のための政策の議論が重要。
  国境調整税に関する議論をしてはどうかとの提案に賛成。
  ドイツ産業連盟では水素輸送コストの議論を始めようとしているが、川崎重工の液体水素船は世界最先端であり、議論に参加してもらえるとよいのでは。
- イノベーションラウンドテーブルで扱うことができるのではないか。

Suggestions for Innovation partnerships

- 企業が共通の関心を持つ領域を探る機会。ただし、企業のマッチングではなく、共通の関心分野を見つけること、機会を提供することが重要。企業にとって貴重な機会になると思慮。
- 国際協力はグリーングロースの一部であり、企業は脱炭素の一部であることから、アイディアに賛成。また、世界の脱炭素を考えた場合、途上国の脱炭素における日独協力の可能性を議論してはどうか。
- ドイツ産業連盟もこの構想に関心を示している。

- 興味深い構想であり、実 PJ につながることを期待。

Expression of thanks and closing remarks by the Co-Chairs

- 脱炭素には技術や政策だけではなく人々の参加が必要。脱炭素は巨大な投資機会でもある。
- 活発な議論に感謝。日本は 2050 年シナリオを策定中で、今回の議論は大いに役立つと思慮。引き続き協力を期待。

以上

付録２．デジタル化とエネルギー変革 AI や分散型エネルギーのビックデータなどデジタル技術を活用した送電運用の最適化

Digitalization and the Energy Transition:

Use of digitalization to optimize grid operation utilizing AI and Big Data collected from DERs

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1 Introduction

The power system is facing a major transformation due to changing consumer demands, more flexible loads and storage, and an increasing share of variable Renewable Energy Sources (VRE), i.e. PV and wind power. This study deals with integration of a higher share of VRES in the distribution grid, combined with increased use of electricity in heat production and transport (sector coupling) using smart grid technology and other digital technologies and Distributed Energy Resources (DERs). Full utilization of digital technologies such as Artificial Intelligence (AI) and big data with Internet of Things (IoT) devices is essential for the effective use of DERs, such as distributed solar PV systems, energy storage, Electric Vehicles (EVs), heat pumps, industrial plants, building systems, or even smart home appliances, which can function for Demand Response (DR). Since DERs are directly connected to the distribution network and an increased deployment of DERs may either ease congestion or cause additional congestion in the distribution grid as well as the transmission grid, the role of the Distribution System Operator (DSO) is particularly important to effectively utilize DERs as flexibility resources with digital technologies. The use of flexibilities from DERs would enable DSO to optimize their own network, maintaining security and supply quality, as supply and demand could be balanced within the distribution network, which could reduce network congestion at the Transmission System Operator (TSO) level.

VRE do not offer much flexibility in themselves to match demand, so their system integration needs other flexibility options to avoid grid congestion and bottlenecks, which is relevant to both Japan and Germany. Digital technologies are essential to improve forecasts of both demand and supply from VRE, and to organize the effective use of flexibilities of DERs in full potential. Big data collected by IoT devices from DERs include real time information on each DER type and connected capacity, consumption pattern, system characters; more specifically, on PV production profile, EV/battery storage charging profile, consumption profile, weather forecasts that are processed by AI combined with other relevant information such as electricity market prices, and network congestion data to provide optimal solutions to avoid congestion and bottlenecks. Also, some sector coupling technologies, such as heat pumps, battery electric vehicles, or electrolysis, may both contribute to grid congestion and offer flexibility. Full utilization of digital technologies is crucial to optimize their operation too.

This study focuses on the use of digitalization for the optimization of distribution/transmission grid operation to avoid congestion and bottlenecks, utilizing AI and big data collected from DERs with IoT devices. The paper progresses as following:

- **Chapter 2** will outline the functions of grid and flexibility operation needed to avoid congestion/ bottlenecks, such as forecasts of both demand and supply from VRE, and organizing the use of flexibilities of DERs (2.1), the uses of digital technologies for each of these functions, in particular AI and big data with IoT devices connected with DERs to utilise their flexibilities and sector coupling (2.2) and the roles of DSO, TSO, DSO/TSO interconnection, DER owners, aggregators and other relevant third parties, in relation to possible business/market models for the functions (2.3).

- In **chapter 3**, experiences to date and current developments/trends, with whatever digital business model, in both countries are described.
- In **chapter 4**, a qualitative discussion of use cases and business/market models identified is conducted.
- **Chapter 5** comprises recommendations that may be possible on policies and regulations.
- **Chapter 6** ends with a conclusion and further research needs.

2 Optimizing grid operation utilizing AI and Big Data: conceptual background

2.1 Functions of grid and flexibility operation needed to avoid congestion/bottlenecks

In smart grids, information and communication technology (ICT) is used to continuously collect data on grid operation, load, and supply, and to automate grid control. The term is related to the distribution system level, since this level traditionally has a lower degree of monitoring, control and automation than the transmission system level. Due to the historical requirement for the distribution system operator (DSO) to distribute power generated in centralized large power plants to customers, the structure and dimensioning of the system is oriented towards the aggregated load of the customers. This practice is currently changing, as customers are changing their load profiles, and variable renewable energies (VRE) are increasingly feeding into the distribution grid. Consumers increasingly participate in prosumer behavior, i.e. the use of their own PV power, and consume additional power by using electric vehicles and heat pumps. As a result, the flow of energy in the distribution grids is becoming highly volatile and, compared to the past, more difficult to predict. This leads to conflicts. For example, market-oriented behavior such as charging the electric car at the most favorable hour is unproblematic in individual cases, but in concentrated form it may endanger the stability of the grid. A first step towards solving the conflict is to gain a better knowledge of the consumers' power demand and of the generation of VRE by distributed energy resources (DERs). Both demand and DER generation forecasting is needed (1) within the DSO system; (2) within the transmission system operator (TSO) system and for the flows between TSO and DSO level.

This chapter analyses the functions in the operation of both the grid and the flexibility options that are needed to avoid congestion and bottlenecks, which will require the use of ICT. Improved forecasting of power demand and of the supply from VRE is one of these functions. Monitoring the status of the grid and coordinated efforts to maintain grid stability and reliability, including the use of the options within the grid to contribute to these targets, is the second broad area. The third broad area of functions is organizing the use of flexibilities of DERs for grid stabilization, which includes both technical aspects of control and metering, and economic aspects of market/incentive, selection, and billing.

Figure 1 shows six emerging functions where the digital technologies, particularly IoT technologies associated with big data and AI, have already been employed or at least tested for flexible grid operation with higher share of VRE to avoid congestion/bottle necks (IRENA, 2019b). They are specifically; improved VRE, wind and solar, generation forecast; maintain grid stability and reliability; improved demand forecast; efficient demand-side management; optimised energy storage operation; and optimised market design and operation. In addition, efficient management of solar and wind generation should not be forgotten, to be added on the left side of the figure at the same level as demand-side management on the right side. Although the curtailment of reduction of solar and wind generation should be avoided to the extent possible, it needs to be available as a flexibility in reserve.

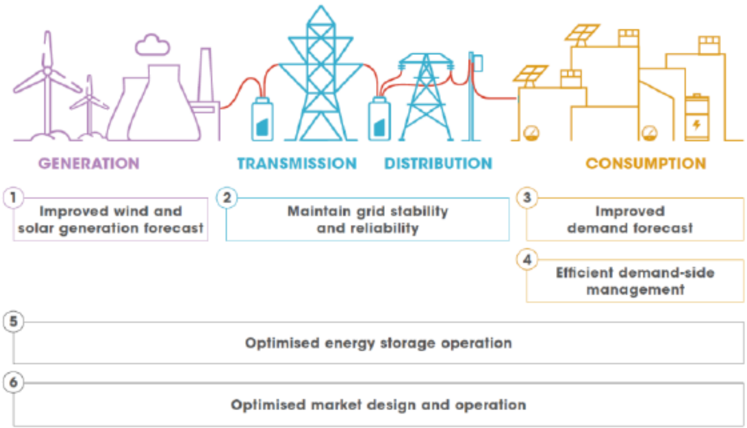

Figure 1: Emerging six functions where the IoT, big data and AI are applied for grid with higher share of VRE. Source: IRENA (2019b)

Forecasts of both power demand and supply from VRE

There are various reasons to improve the **forecasting of power demand**. It is an important issue of economic and safe operations planning in power distribution systems. Basic operations of the power systems such as economic dispatch, unit maintenance, fuel scheduling and unit commitment can be performed more efficiently by having more accurate demand forecasts. There are three basic time scales when it comes to the forecast of power demand, comprising short-term, mid-term and long-term forecasting and related applications (see Table 1).

Time scale	Application
Short-term forecasting (an hour to a week)	Scheduling and analyses of the distribution network
Mid-term forecasting (a month to 5 years)	Planning the power production resources and tariffs
Long-term forecasting (5–20 years)	Resource management and development investments

Table 1: Demand forecasting time scales and applications.
Source: own illustration based on Ghalehkhondabi et al. (2017)

Obviously, short-term forecasts are most relevant for the daily operation of a DSO system. However, mid- and long-term forecasts are important for forecasting and planning the need of upgrades to the grid and/or the flexibility options. These will, in turn, enable a secure daily operation of the grid in the future.

Forecasting methods can be further divided into causal and historical data-based methods. In the causal methods, the energy consumption serves as the output variable while economic, social, and climate factors serve as input variables. Artificial neural networks (ANNs) and regression models are the most frequent causal methods used to predict the energy demand. Methods based on historical data use the previous values of a variable to forecast the future values of that variable. Time series, Grey prediction and autoregressive models are among these methods.

According to a literature review conducted by Ghalehkhondabi et al. (2017), the most-applied energy demand-forecasting models for short-term electricity demand are: Artificial neural network models; Fuzzy logic; Time series models; ARMA, ARIMA, SARIMA; Regression models; and Support vector machines. Other models, such as Grey (gray) prediction; Genetic Algorithm; Econometric models; and System dynamics models are more relevant for mid- and long-term forecasting.

New loads, such as battery electric vehicles or storage, and heat pumps, add to the complexity of load forecasting, and require adaptation of results from methods based on historical data.

Forecasts of the generation from VRE units are needed in order to know in advance the amount of power that wind turbines or PV modules will feed into the grid over the next hours and days. The VRE forecasts are generally based on forecasts of the weather conditions at the site locations. To match the different requirements, several time scales of forecasts are used (see Table 2).

Different kinds of stakeholders make use of the predictions: Energy traders, who have a contract to sell VRE for the plant operators, use the forecasts for trade on the intraday and day-ahead energy market, control of curtailment due to negative market price, correct activation of regulation power and participation in the regulation market. Together with speculators, they can also use forecasts to predict the influence of VRE on the market price. The main fields of application for grid operators, load dispatch centers and independent system operators are balancing, unit (re-)dispatch, curtailment of power plants, load flow calculations, Day-Ahead and the Two-Days-Ahead Congestion Forecast (DACF and 2DACF) and week-ahead planning. The last group of stakeholders are VRE operators. They use supply forecasts for day-ahead and medium-term planning of maintenance. Owners of a roof-top PV installation also plan the consumption of their households by means of the forecasts to raise the share of internal consumption of the produced energy.

Time frame	Application	Stakeholders
Shortest-term forecast (0 – 6 hours)	Trading on intraday energy market, control of curtailment due to negative market price, correct activation of regulation power	Traders
	Influence of VRE on market price	Speculators
	Balancing, unit re-dispatch, curtailment of power plants	Grid operators, load dispatch centers, independent system operators
Short-term forecasts (6 – 48 hours)	Trading on day-ahead energy market, participation in regulation market, Influence of VRE on market price	Traders
	Unit dispatch, load flow calculations, DACF congestion forecast	Grid operators, load dispatch centers, independent system operators
	Day-ahead planning of maintenance	VRE operators
Medium-term forecasts (2 – 10 days)	Trading on long-term markets	Traders
	2DACF congestion forecast, week-ahead planning	Grid operators, load dispatch centers, independent system operators
	Medium-term planning of maintenance	VRE operators

Table 2: VRE forecasting time scales, applications and stakeholders.
Source: own illustration based on Zieher et al. (2015)

For most applications, there are specialized forecast service providers. They operate on a commercial basis and supply regular VRE power forecasts, similar to weather forecasts. In contrast to this, in-house concepts require a lot of effort in terms of meteorological know-how and resources (human as well as IT infrastructure) to achieve a high forecasting accuracy.

To realize a service solution, it makes sense to establish a centralized approach where one responsible stakeholder, e.g. grid operator, ISO or trading company, receives forecasts for all VRE units of the portfolio from one or more forecast service providers. Hence, the forecasts are not collected from the individual VRE operators. Experiences from other countries show that only a centralized forecasting approach ensures high quality across all VRE units. Especially for large portfolios it is good international practice that all required data from the VRE units, i.e. power production, availability information etc., are collected by the buyers of the power, such as aggregators/traders on the market, DSOs or other customers, and are then made available to the forecast service providers.

There are two steps to be taken to forecast the power supply of VRE. First, the weather for the relevant VRE units has to be predicted. Then the meteorological variables have to be translated into predictions for power generation.

Established wind and solar power prediction systems generally use numerical weather models (NWP) as input. NWP models divide the atmosphere into little boxes (grid cells) with finite spatial extension. They represent on average what is happening inside this box. In horizontal direction, the size of grid cells can vary between a few hundred meters and 20 kilometers. The vertical direction is important to consider as well. In general, the lower levels, which are important for VRE forecasting, are covered by non-equidistant steps, typically around 10 m, 30 m, 100 m or 200 m. For wind power forecasts it is very crucial to calculate the wind speed at hub height of the wind turbines as precisely as possible. The forecasting systems differ widely in the way they perform this vertical interpolation.

The crucial second step of wind and solar power forecasting is the conversion of the meteorological variables, e.g. wind speeds or solar irradiance, into power output of VRE units. There are two main approaches to carry out this conversion: the statistical approach and the physical approach. In statistical systems, a mathematical relation between numerical weather predictions as input and measured power output is “trained” or “learned” based on the available data. In contrast to this, physical systems use methods from boundary layer meteorology and irradiance transfer schemes to calculate the right meteorological input, e.g. wind speed at hub height, and then use power curves to transfer it into power.

Compared to PV and wind, the power generation from other DERs like combined heat and power (CHP) plants, biomass and hydroelectric power is typically more predictable and also able to provide a higher flexibility in most cases.

Monitoring the status of the grid

Matching supply and demand in a DSO system based on improved forecasting, as discussed in the previous section, is an important step to avoiding grid congestion or bottlenecks at the connections with the transmission system or neighbouring DSO systems. Still, the status of the connections may be different, and there may also be internal differences in substations and imbalances at the low-voltage level. Therefore, monitoring the status of all grid components is an important additional function.

Maintaining grid stability and reliability

In order to maintain grid reliability, the monitoring data on the grid status has to be processed and assessed in regard to stability and risks. Only then there can be a proper reaction to stability risks by activating resources in the grid itself, such as switching, controllable transformers, or allowing higher power line temperatures depending on weather circumstances, as well as flexibilities of both DERs (see below) and conventional plants. For example, an Active System Management (ASM) is a key set of strategies and tools performed and used by DSOs and TSOs for the cost-efficient and secure management of the electricity systems. It involves the use and enhancement of smart and digital grids, operational planning and forecasting processes and the capacity to modulate, in different timeframes and distinct areas, generation and demand encompassing flexibility instruments to tackle challenges impacting system operation. It thus ensures proper integration of Renewable Energy Sources (RES) and a high share of Distributed Energy Resources (DER), as well as the integration with energy markets.

Organizing the use of flexibilities of DERs

The term smart grid is often understood comprehensively and includes not only IT-supported transmission and distribution of electricity but also power generation, storage and consumption. In this context distributed energy resources (DERs) are of central importance. The term comprises small-scale distributed generation (DG) and energy storage units as well as demand response (DR) tools connected to the distribution system. DERs could be actively incorporated in the operation of distribution grids providing certain flexibility. Such DER flexibility is generally associated with temporal shifting of energy, i.e. for consumption or injection, in reaction to an external signal (price signal or activation).

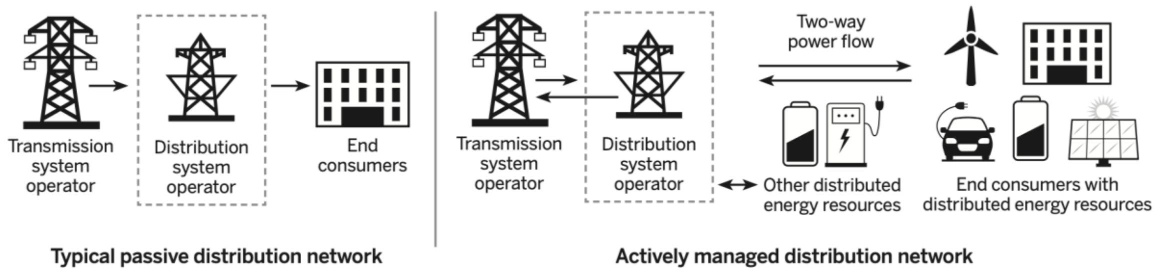

Figure 2: Traditional and modern distribution networks.
Source: IRENA (2019a)

Types of DERs and flexibilities

Distributed generation

Small-scale distributed generation technologies include: Wind and PV (VRES), biogas and biomass power plants, small-scale hydro (usually run-of-the-river), and CHP plants (Ecofys et al. 2015).

Wind turbines and PV installations have the technical capability for providing fast response to regulation signals. By curtailing power production, these installations can provide down regulation. Up regulation can be provided by operating units at generation levels below their potential generation value at a given time, and increasing to the normal level if needed. Both operations come at the expense of an overall reduction in VRE output. A similar potential and trade-off is connected to **run-of-the-river hydro** power plants without a possibility for water storage.

The electricity production via **biogas plants** makes use of Gas-Otto-engines which can ramp up and down in seconds. [*But flexibility in the biogas production itself is very limited.*] The reaction time expands over several hours to days. It could be ramped to about 50% of the capacity. Biogas storage facilities are usually constructed to store 3 – 6 hours of biogas production and could be enlarged for provision of flexibility. **Small-scale hydro** power plants with an upper reservoir hold similar characteristics to biogas.

CHP plants produce electricity by heat that is generated from a central process. CHP plants using internal combustion engines and gas turbines, which is typical for small to medium CHP plants, are typically inflexible resources for the power system as their electricity output is constrained by the heat requirements of the process connected to the CHP. CHP can become provider of flexibility with the integration of heat storage, in order to decouple the generation of electricity and of heat to a certain extent.

Demand response

The organized energy market places typically have strong and active supply sides (generators), but rather weak and inactive demand side (customers). The involvement of the customers, independently of whether they are prosumers or pure consumers, is likely to be vital for the successful integration of DERs. The key will be to enable participation of the customers that have the underlying potential for flexibility, e.g. factories with their production processes and heat, cold, or compressed air supply, frozen or chilled food warehouses, or large buildings with electric heat pumps or significant cooling demand.

In the residential and in the commercial sector, demand management can especially be applied in cross-section processes such as providing heating and cooling. This includes different levels of electricity demand, e.g. selective timing of the cooling of cold storage warehouses as well as automatic adjustments in the demand of refrigerators. Other potential demand management technologies include air conditioning, compressing air for mechanical use or even rescheduling of washing processes in households. However, although the high number of residential customers may yield a high total potential, it is usually less cost-effective to harness it than the potential that exists with industrial and commercial customers.

Distributed storage

Small scale storage options can provide flexibility on distribution grid levels by enabling time-shifting of local demand and supply.

Pumped hydro storage (PHS) stores energy mechanically. Electricity is used to pump water from a lower reservoir to an upper reservoir and recovering the energy by allowing the water to flow back through turbines to produce power, similar to traditional hydro power plants. Pumped hydro storage power plants are common technology and by far the largest-capacity form of grid energy storage available today. Because of their cost-optimal size, they are typically connected to the transmission network.

Power to Gas refers to chemical energy storage, namely the use of electric energy to create fuels that may be burned in CHP or even conventional power plants. Key fuel expected for the future is hydrogen (and synthetic methane produced hydrogen to some degree). Methane is the main constituent of natural gas and therefore can be injected to the existing infrastructure for natural gas (grid and storage). The high storage capacity of the gas grid could then be used for medium- and long-term storage purposes. Alternatively, parts of the gas grid could be converted to a hydrogen grid. Power to gas allows long-term storage, e.g. of PV power from the summer to flexible power production in winter.

Furthermore, **battery technologies**, e.g. conventional (lead acid, lithium ion), high temperature batteries and flow batteries, can provide power storage options. Batteries have a very fast response time and high efficiencies, but they have high capital costs. Similar to those battery technologies, fleets of EVs can be used as a flexibility option for the power system. There are two key operational modes: **Grid-to-Vehicle** (G2V), where fleets of EVs are operated as a demand side management option, enabling a shifting of the charging times or **Vehicle-to-Grid** (V2G), where in addition to charging, the batteries of EVs could be discharged and feed power to the grid. Due to their primary use as means of transportation, the provision of flexibility from EVs is subject to many constraints and is inherently uncertain.

Smart Grid technologies

In addition to DERs connected to the grid, there are also flexibility options through Smart Grid technologies, such as controllable local transformers or high-temperature power cables. These are not in the focus of this report, but should still be mentioned.

Functions for the use of flexibilities from DERs for grid stabilization

There are several technical and economic functions needed for the use of flexibilities from DERs and grid stabilization.

Technical functions include **control** and **metering**. Obviously, in order use flexibilities, they need to be put in operation or stopped again by a technical control. Control can either be conducted by the DER operator based on a contract and a financial incentive, or by the grid operator. DERs are either under remote/automatic or under manual control. Direct control methods are well-suited for short-term provision of flexibility services, particularly of those which require a very precise location of activation like voltage control and congestion management.

In any case, the impact of the use of a flexibility on power generation, demand, or storage needs to be metered. In addition to traditional costly load metering, the future metering technology appropriate to cover the use of flexibilities is expected to be smart metering, which includes load metering and gateways for real-time transmission.

These technical functions are a precondition to make full use of **economic functions.** These include the **design, installation and operation of flexibility markets or incentive programs**; and for their operation, the **offer and selection or activation of flexibilities** in these markets or following these incentives; and the **billing** of the flexibilities used.

If flexibilities of DERs are established via a flexibility market organized by or for the DSO, prequalification of flexibilities will be the first step; offering or tendering by the DER operators will be the second; and selection of flexibilities using certain routines will be the third.

Regarding the details of how to establish the function of optimized market design and operation, it may be possible to learn from markets for balancing and ancillary services that are already established at the transmission system level (Ninomiya et al. 2019). Ancillary service markets are in place in order to manage transactions for upward or downward adjustments in the short to very short term. These markets are organized very close to real- time and require automated load adjustment. Markets for balancing services are arranged longer before real- time than ancillary services. Due to the fact that individual DERs do not provide sufficient reliable electric flexibility to be tradable in markets and their size is usually small and hence, transaction costs are too high for them to participate in the market individually, aggregation is required in order to trade in organized markets. At high voltage levels under responsibility of the system operator, trading mechanisms like contracts for ancillary services and balancing markets already provide opportunities for economic efficient supply of system flexibility services. In a situation with smart metering and real-time management of distribution networks, similar arrangements could be enabled for medium- and low-voltage levels.

With controllable DERs, the system operator, aggregator or even retailer could make the end user agree to automatic control (upward or downward) of the operation of the DER equipment. This control could be price-driven in the offering/tendering and selection phases, like in wholesale or balancing market trading of flexibility. Finally, all of these events of flexibility use will need billing, which can be based on smart metering data.

An alternative to a regional flexibility market could be time-dependent grid tariffs or even real-time pricing for the grid tariff, and self-selection of flexibilities by DER operators in reaction to these price signals. Possibilities with smart metering and real-time pricing allow for the increase of cost causality with tariff design, meaning that the electricity prices reflect the actual costs for delivering the service, which may become very high in times of grid congestion. However, if consumers have to react individually to price signals, the potential for aggregated DR flexibility will be very low. Billing will not be needed in this setting to incentivize the flexible reaction of DERs, since they react to price signals.

The actual reality of pricing is quite complex, as shown in Table 3 below. Depending on time span and purpose as well as TSO or DSO level, there are a variety of different pricing models available. For grid interactions which require response between 1 to 30 min before real-time, direct load control would be suited in order to secure response of this DER. Appropriate DER for such short notification time periods would be most DER except for CHP units due to their longer ramp-up times, although capacity-type DERs would be more efficient than energy-type DERs. Furthermore, PV units would not be dispatchable as positive flexibility due to their generation dependence on weather conditions; however, in combination with storage, flexibility trading could be enabled. For longer notification times of 30 min to 1 h, all other pricing methods could be suited (see Table 3) and decisions should be further dependent on socio-economic factors like user characteristics of price elasticity and the availability of home automation. All DER types would be appropriate for supplying flexibility for longer than 1 h of activation time, except for short-term duration batteries or other short-term energy storage. For the very long term, critical peak pricing and time of use pricing are appropriate due to the possibility to settle those prices on a yearly basis (Eid 2016).

Notification time before real-time	Appropriate incentives or control method for DER management	Related markets for electric flexibility trading	Appropriate DER
< One minute	Direct control	Frequency control (primary, secondary, tertiary reserves), voltage control	EV, Continuous loads (heating/cooling, light-ning), EES
1–15 minutes	Direct control	Network restoration, voltage control	EV, Continuous loads (heating/cooling), EES
15–30 min	Direct control	Network restoration (HV/LV), Balancing market, Portfolio balancing	EV, EES, CHP units Continuous loads (heating/ cooling), dispatchable loads
1 hour	Direct control, ICAP*, Emergency demand response, Real time pricing, Peak time rebates, Critical Peak Pricing	Balancing market, Network Congestion Management	EV, EES, CHP units Continuous loads (heating/ cooling), dispatchable loads
1 - 48 hour	Direct control, ICAP*, Emergency demand response, Real time pricing, Peak time rebates, Critical Peak Pricing	Spot Market (Day ahead and Intraday market)	EV, EES, CHP units Continuous loads (heating/ cooling), dispatchable loads, PV units with storage
Year ahead	Critical peak pricing, Time of use pricing	Deferring network investments (HV/ LV), generation investment peak reduction	EV, EES, CHP units Continuous loads (heating/ cooling), dispatchable loads, PV units with storage

*Interruptible capacity programs

Table 3: Relationship between notification times, appropriate incentives and markets for DER flexibility trading. Source: Eid (2016)

2.2 Uses of digital technologies for each of these functions

This section overviews digital technologies employed for the various functions of flexible grid operation to avoid congestion/bottlenecks analysed in the previous sections. Decisions on grid management have been traditionally taken on a manual basis by skilled operators, in some cases, augmented by elementary automation systems. However, as mentioned in the previous section, substantially rapid growth of distributed RE plans and other DERs have brought increasing difficulties in decision making on grid operation in the traditional manner. Therefore, increased use of digital technologies is needed. There are many different types of technologies that can be used for the functions of flexible grid operation to avoid congestion/bottlenecks. However, due to the increasing complexity and decentralization of the grid with the increasing number of DERs, the Internet of Things (IoT) and Artificial Intelligence (AI) using big data stand out in importance. This is why we first address these two types of digital technologies and their potential uses for the functions of flexible grid operation, before we conclude with an overview of the technologies that can be used for each function.

The IoT (Internet of things)

The IoT technologies are essential to enable the functions being realised. IoT technologies can provide connectivity between physical devices such as power plants, power grid, energy appliances and industry equipment, employing sensors and communication technologies for monitoring and transmitting real-time data which enables fast computations and optimal decision-making (Schulz et.al., 2020). In addition, actors and data transmission for changes in operation are equally important parts of the energy IoT. The IoT is a general concept which captures a range of individual technologies for monitoring, networking, computing and control devices as an automated integrated system. The often-heard notion of “smart grids” can be considered as an advanced power grid empowered by the IoT technologies. In other words, the IoT is a key element of smart grids.

The IoT is expected to enormously contribute to grid stabilisation with higher a share of VRE by optimizing the grid by monitoring/controlling supply and demand side. Demand-side management, also known as demand response, is of particular importance, since a greater potential of flexibility concealed in demand-side could be unlocked only by broad application of the IoT. In order to harvest the demand response potential, particularly the tremendous but dispersed residential potential, investment in information and communication technologies (ICT) is necessary. Smart appliances and equipment, home/ building/ plant automation and smart meters are the main instruments to tap this potential. ICT technology can facilitate the interoperability of smart devices. Interoperability will depend heavily on standardization of appliances and of the different communication devices.

Hardware of the IoT technologies is divided into four categories; systems for data collection; systems for communicating data; systems for computing and analysis based on the data; and control devices. The first includes smart meters with high-resolution metering data/sensors, sensors installed in different devices. The second includes ICT infrastructure such as fibre cables, Internet, wireless communication, etc. The third comprises all kinds of models of the grid or the markets and their assets. The fourth category, for the energy IoT, includes all kinds of flexibilities in the grid and in demand, generation, and storage, such as battery storage devices at distribution level, upgrading network assets to handle unexpected large reverse of power flow, active network devices such as automatic on-load tap changers for transformers, static synchronous compensators, static var compensators and others (IRENA,2019c).

Software is also necessary for data collection, data pre-processing including smart meter data acquisition software and SCADA software. In addition, communication protocol is indispensable for data transfer between different parties involved. Therefore, it is required to develop common interoperable standard for both the physical/information/ICT layers and cybersecurity protocol (IRENA, *ibid.*).

Not only hard/software, but relevant policies and regulations are also needed for development of the IoT (see chapter 5). For instance, it is vital to encourage DER owners to participate in the market so that DER owners are incentivised for installation of the IoT devices in their DERs. It is also important to encourage data exchange and improved communication on a transparent basis. In parallel to these, appropriate policies/regulations for end consumers private data also need to be established to protect their privacy.

AI and big data

Once the IoT devices are installed on a larger scale, a massive amount of raw data could be collected by them. Such a dataset is called "big data" which does not have much value itself. The big data need to be processed by Artificial Intelligence (AI), e.g., under a cloud computing service, in order to be utilised effectively as valuable figure to control DERs as flexible resources for the power grid. Having a large amount of big data collected by the IoT, AI could automatically provide insightful information for decision making on generation, grid and DERs simultaneously to avoid congestion and bottlenecks effectively which has been almost impossible without the IoT, big data and AI.

In fact, none of the IoT, big data and AI works alone for optimisation of grid with higher share of VRE. They have to be integrated each other as a system. AI without big data simply does not work, since AI needs big data collected by the IoT ideally installed at entire power system in order not only for decision making on grid operation but also for self-leaning process by AI itself. Similarly, the IoT generates big data which alone itself does not mean anything for grid operation as mentioned above.

Apart from a large amount of big data, AI obviously requires a particular software, which is specific to the AI technology used in a system and is operated on a cloud computing platform in most of the cases. In addition, human expertise of data scientists who develop machine-learning algorithms and continuously improve models as the share of VRE increases is vitally important. Similar to the case of the IoT, development of cybersecurity protocols is also necessary as electricity grid and digital technologies further interconnected are implying that cyberattacks could become enormous risks on the essential social infrastructure.

Given the recent development of DERs and the increasing complexity of grid operation, the IoT, big data and AI would enable a large number of RE plants and DERs to be flexible resources not only for optimisation of grid operation but also optimisation of RE plants, electricity consumers, hence a higher share of VRE can be accommodated in the grid while maintaining a secure supply.

Among the functions illustrated in Figure 1 and chapter 2.1, improved VRE generation forecast is one of the main applied areas, in which the IoT, big data and AI have been employed. The IoT technologies used in this application are, for example, various sensors installed individual RE plant for real time measurement of parameters related to power generation such as wind speed and solar irradiance at the location of each plant. These sensors seamlessly produce big data, which is fed into AI with other relevant data including meteorological data, earth observation satellite data and sky image data and other relevant public sensors data if any available. Having big data and other relevant information, AI could more accurately forecast generation, which can be utilised by grid operators to improve unit commitment, increase dispatch efficiency and reduce reliability issues and operating reserves (IRENA, 2019c).

Summing up: Uses of digital technologies for the smart grid and related market functions

The following table sums up what are the uses of digital technologies for each of the functions of grid and flexibility operation needed to avoid congestion/bottlenecks identified in chapter 2.1. Among the digital technologies used for these functions are different forms of IoT and AI, including for example grid models and smart meters, and their accompanying infrastructure and software.

Functions of grid and flexibility operation needed to avoid congestion/bottlenecks	**Uses of digital technologies for these functions**
Improved demand forecast	IoT (to collect smart meter data with high time resolution) and AI to recognize patterns and improve forecasts
Improved wind and solar generation forecast	IoT (to collect generation and weather data with high time resolution) and AI to recognize patterns and improve forecasts; possibly also physical approaches
Monitoring the status of the grid	IoT (to collect status data from grid components in real time)
Maintaining grid stability and reliability	Grid models able to integrate and assess demand, generation, and grid status data and to calculate trends and forecast risks of congestion, including through AI
Control of DERs: efficient demand-side and solar and wind generation management; optimized operation of energy storage and further flexibilities	IoT to collect status data and to activate changes in operation, if these can be activated automatically; otherwise, safe and reliable control data transmission to decision-makers
Smart Metering	Smart meters and safe data transmission (which are a part of the IoT)
Optimized market design and operation	Server infrastructure and software for optimized market operation
Offer and selection or activation of flexibilities	Protocols or smart contracts and software for offer, selection, and activation of flexibilities
Billing	Software (e.g., blockchain) for billing

Table 4: Uses of digital technologies for the smart grid and related market functions

2.3 Roles of DSOs, TSOs, DSO/TSO interconnection, DER owners, aggregators and other relevant third parties in relation to possible business/market models for the functions[1]

Roles of DSOs

As repeatedly mentioned, VREs, batteries, EVs and other DERs have rapidly increased over the past years. They brought less-predicted power flow in the grid. Some of them may be used to contribute to maintaining grid stability and reliability, some may cause events of grid congestion in the distributed area, and sometimes both effects are possible. In this circumstance, DSOs are expected to change their role from conventional one-way power flow operation to two-way operation shown in Figure 1. DSOs could benefit from the flexibilities of DERs by taking their advantage of directly connecting to DERs. With digital technologies, DSOs could monitor and collect real time/past data of DERs which can be processed by AI and used for their grid management. When the regulatory framework and the contract allows, as part of optimization of the distribution grid, DSOs are expected to procure flexibilities from DERs and even directly control DERs.

In relation to the functions of gird operation needed to avoid congestion/bottlenecks discussed so far, the expected roles of DSOs can be; 1) establishment of contracts between DSOs and DERs owners for installation of the IoT devices on each DER; 2) installation of the IoT devices on DERs and monitoring/collecting real-time data from DERs; 3) processing the data or providing the data to TSOs or the third-parties such as aggregators/Energy-as-a-Service (EaaS) to be processed by AI; 4) use of flexibilities offered by DERs to optimize the distribution grid according to the result given by AI or acting as neutral market facilitators and providing high-resolution price signals to the DERs owners, or possibly by organizing a regional flexibility market.

Consequently, DSOs could increase flexibilities in their distribution grid, leading to reduction of their investment in grid reinforcement/expansion. In addition, the data collected from DERs could be fully utilized by TSO and the third-parties allowing even higher share of VRE.

Roles of TSOs and DSO/TSO interaction

A massive increase in DERs and shift to two-way power flow have brought an impact not only on distribution grid, but also on transmission grid since the distribution grid is one the components of the transmission grid. TSOs only indirectly connect to DERs through DSOs as shown in Figure 1[2]. Therefore, the roles of TSOs in connection to usage of DERs can be extremely limited without an interaction between DSO and TSO. Not having any information on DERs, TSOs would face a difficulty in accurate forecast of the generation from VRE and power demand of the final consumers, and lose the opportunities to utilize DERs as flexibility resources. If or not potential flexibilities of DERs can be fully utilized for the power system can be highly depending upon efficient coordination

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[1] This section largely refers to IRENA (2020a, 2019a, 2019b).

[2] Some renewable energy generation facilities are directly connected to the transmission system, such as offshore or big onshore wind farms. However, these are then not considered DERs, so the statement that TSOs are only indirectly connected to DSOs remains valid.

between DSO and TSO. The critical factor here is efficient data exchange between them on capabilities of DERs. Figure 3 presents some of key areas of coordination between them (IRENA, 2020a).

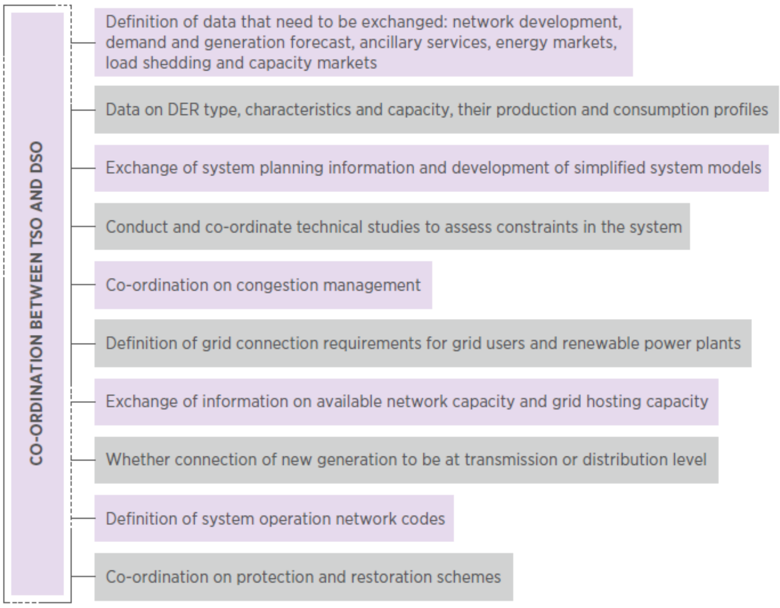

Figure 3: Key areas of coordination between DSOs and TSOs.
Source: IRENA (2020a)

In this framework, DSOs are expected to be a data exchange platformer between DERs and TSOs and other relevant parties to provide the required information of DERs to TSOs.

When DSO and TSO interact, the role of TSOs can be 1) definition of the required data collected from DERs to be exchanged between DSO and TSO such as type, characteristics, capacity, their production/consumption profiles of DERs; 2) exchange of the required data which could be fed into AI; 3) use of flexibility offered by DERs to balance the transmission grid according to the result given by AI. In addition, TSOs may be given the task to organize the reserve control markets, as it is the case in Germany, and can directly include DERs at least in this way.

Using the flexibility of DERs in coordination between DSO and TSO, the benefits gained by TSOs are significant so that they can increase their system flexibility and differ their investment on grid reinforcement/expansion as the system could accommodate increasing number of VRE without additional investment.

Roles of DER owners

The role of DER owners is also expected to change significantly. Most of DER owners have been in a position like “install DERs and do nothing” so that DERs have hardly ever been recognized as flexible resources. Under the new environment where VRE and DERs substantially increase, at least some of them are likely to change into active market players to react to market conditions and making profits by changing their demand, namely demand response, and generation pattern with the support of digitalization technologies. An installation of IoT devices under the contract to DSOs or aggregators would be a starting point. The data collected by the IoT devices are fed into AI providing the solution for decision making on changing their demand and supply profiles to maximize their profits, which could be automatically executed by IT. This would increase flexibilities in the grid system which may be a benefit for DSOs and TSOs as already discussed. However, if DER owners and aggregators only react to the price signals of the energy markets, this will not take grid constraints into account, as discussed in our study on P2P energy trading and PPAs (Ninomiya et al. 2020). The regulatory and practical preconditions need to be created to make these DERs beneficial for the DSOs and TSOs as well.

The roles of DER owners, in relation to the functions of grid operation needed to avoid congestion/bottlenecks, can be 1) changing their position from "humble ratepayers" into active market players to maximize their profits by fully utilizing their own DERs as flexible resources; 2) installation of the IoT devices on their DERs under the contract with DSOs or aggregators allowing them to collect real-time data of DERs behaviour and feed it into AI process; 3) undertaking actions as active market players reacting to the price signals in the markets based upon the solution given by AI. In this case, DSOs or aggregators are expected to act as market facilitator to provide appropriate solution given by AI to DER owners.

Roles of aggregators

Aggregators who aggregate DERs and operate them on behalf of DER owners to trade their flexibilities in the market are also important actors in relation to the functions of gird operation needed to avoid congestion/bottlenecks. At the present, most of aggregators engage with a limited number of relatively large scale of DERs, for instance more than 100 kW capacity in the case of Next Kraftwerke in Germany. Therefore, flexibility resources of these large scale DERs have already been utilized at least in the grid management of TSOs in a certain extent. Nonetheless, when the costs of digital technologies – in particular, of smart meters – significantly decrease in the future, the threshold, say 100 kW, is likely to be much lower, suggesting that a far greater number of small-medium size of DERs such as EVs, rooftop solar PV and heat-pumps may be aggregated by aggregators. In such a case, the roles of aggregators may be more or less similar to those of DSOs discussed above. The major difference can be that aggregators position between DERs and DSOs as an intermediary to provide flexibilities of DERs to DSOs, but also on electricity, capacity, and reserve control markets. If the coverage of DERs by aggregators considerably widens in this way, DSOs may no longer need to install the IoT devices on DERs and collect big data by themselves. Since installation and operation of the IoT devices on small-medium size DERs can be the costliest elements of the system, the future consequence of "who shall do this", more specially DSOs or aggregator, is still not clear yet at this stage. The result would depend upon the cost reduction of the digital technologies, demand for flexibilities of small-medium DERs and profits margin of trading such flexibilities in the markets. If none of these conditions are met, then, economic incentives for installation of the IoT devices on small-medium DERs can be largely diminished.

Roles of other relevant third parties

Other parties are mainly relevant for the market-based functions (such as market operation, offer and selection or activation of flexibilities, and billing) in using DERs and IT solutions, e.g.

- private operators of energy marketplaces

- unbundled energy suppliers or P2P energy trading platformers, which could take similar roles as aggregators if they engage in connecting DERs and making them flexible.

Finally, regulators also play an important role by allowing or not, and setting the rules, for the use of DERs in optimizing grid operation and avoiding bottlenecks.

Summing up: Roles of actors in relation to business/market models for the functions of grid and flexibility operation

The following tables sums up the roles of actors in relation to business/market models for the functions of grid and flexibility operation needed to avoid congestion/bottlenecks identified in chapter 2.1. Different actors make use of these functions: consumers, TSOs, DSOs, aggregators, generators, suppliers, (flexible) DER owners, smart meter operators, and operators entitled or accredited to create and/or operate a market. Sometimes, several types of actors have an interest to use one of the functions for their business models and operations, for example in the case of improved demand forecasting. They all could make use of the digital technologies identified in chapter 2.2.

Functions of grid and flexibility operation needed to avoid congestion/bottlenecks	**Roles of actors in relation to business/market models for these functions**
Improved demand forecast	Consumers for optimizing their bills TSOs, DSOs for forecasting grid status and maintaining stability and reliability; TSOs for the reserve control market Aggregators for optimizing the use of generators and flexibilities Generators for optimizing their generation Suppliers for optimizing their purchasing portfolio and their balancing group
Improved wind and solar generation forecast	Generators for maximizing their revenues/profits TSOs, DSOs for forecasting grid status and maintaining stability and reliability; TSOs for the reserve control market Aggregators for optimizing the use of flexibilities and generators Suppliers for optimizing their purchasing portfolio and their balancing group
Monitoring the status of the grid	TSOs, DSOs for forecasting grid status and maintaining stability and reliability
Maintaining grid stability and reliability	TSOs, DSOs for maintaining grid stability and reliability
Control of DERs: efficient demand-side and solar and wind generation management; optimized operation of energy storage and further flexibilities	DER owners for maximizing their revenues/profits Aggregators maximizing their revenues/profits DSOs or TSOs if they have direct control
Smart Metering	Smart meter operators
Optimized market design and operation	Operators entitled or accredited to create and operate a market, e.g. private electricity exchanges, TSOs for reserve control markets, DSOs for regional flexibility markets
Offer and selection or activation of flexibilities	Market operators Flexible DER owners: offer in markets; activate if not done automatically, or if they self-select in response to incentives from DSOs
Billing	Suppliers, market operators, aggregators, DER owners, etc.

Table 5: Roles of actors in relation to business/market models for the functions of grid and flexibility operation.

3 Digital business models in Japan and Germany

3.1 Japan

3.1.1 Experiences to date

In Japan, utilization of DERs for operation of the local distribution grid, particularly for elimination of grid congestion and voltage control, has seen little activity compared to the case of Germany (see below chapters), irrespective of the availability of digitalization technologies. Several reasons can be given for this contrasted status. First, unlike Germany, distribution grids have been owned/operated by TDSOs, which were parts of the monopolized large vertical integrated utilities until recently, in place of local independent DSOs, over the past nearly 70 years after the World War II. This implies that the roles of distribution grid operation have been considered to be subordinate compared to transmission grid operation and often characterized by “connect DERs and forget”. In other words, DERs have rarely been in the situation where local DSOs actively utilize their flexibility for the grid management. Second, the share of VRE in annual electricity generation in Japan, 8% in 2019, is much lower compared to Germany of 28% in 2019. Hence, apart from some exceptional cases in specific areas, congestion of distribution grids caused by a rapid increase in DERs has not been broadly perceived yet as an urgent issue to be addressed as much as the same degree done by Germany. It is no wonder that utilization of DERs for distribution grid management has not been activated in Japan since simply not much necessity for such use of DERs has boosted. In addition, the lower share of VRE conversely means the higher share of non-VRE, indicating that, in Japan, a sufficiently large amount of flexibility resources from conventional power plants, for instance, pumped hydro of 22GW plus oil power plants of around 20GW are still available to provide rapid balancing service. This also has created lesser incentive to use DERs as flexibility resources for grid management, especially for transmission grids. Putting it simply, DERs have not been “desperately needed” for grid management in Japan so far.

However, this situation would change dramatically in the near future. An accelerated increase in VRE is expected in order to achieve the carbon neutral commitment by 2050 declared in October 2020. Though a detailed roadmap how to reach the decarbonized economy has not been established, a substantial increase in renewables, particularly VRE, will be essential over the next decades. At the same time, not only renewables but also other DERs such as EVs and batteries are also expected to increase substantially. Such increase in DERs would lead to congestion of local distribution grids, for which effective use of DERs by grid operators is likely to become necessary. Moreover, following the recent amendment of the electricity industry law, after 2022, distribution grids can be independently operated by local grid operators with proper legal license, namely DSOs, who may develop incentives to utilize the DERs directly connected to their distribution grids in order to eliminate their grid congestion and provide other services.

3.1.2 Current developments/trends

The recent change in the environment around distribution grid calls for further actions towards effective use of DERs by DTSOs, or possibly DSOs after 2022, for their management of local distribution grids. So far, most of the demonstration projects for effective use of DERs conducted in Japan have mainly focused on the roles/ functions of aggregators rather than grid operators within the framework of VPP and electricity markets. In those projects, it is implicitly assumed that aggregators are acting as main hubs of information gathering taken from DERs via IoT and other digital technologies. In such case, aggregators directly monitor/ control DERs corresponding to the markets, VRE generation forecast and other relevant parameters, whilst grid operators could only indirectly monitor/control DERs through aggregators. While distribution grids physically directly connect to any DERs for power their supply by definition, information on the behavior of DERs is not directly delivered to them, as shown in the following Figure 4.

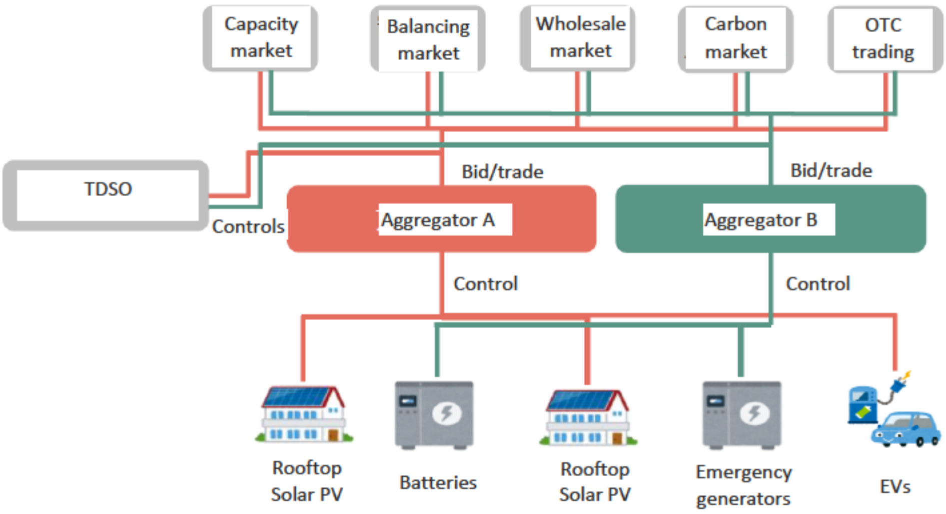

Figure 4: Overview of the existing VPP model: aggregators act as DERs information hub.
Source: METI (2020)

In this business model, once again, TDSOs cannot directly monitor the DERs, which may result in facing a difficulty of clear understanding and identification of each DER, and controlling the DER by all means.

In contrast to this existing VPP model, a new framework has been presented where grid operators, TDSOs, or DSOs in specific cases, themselves establish a management platform on DERs for which all of relevant information on DERs, monitored via IoT embedded each DER, is collected intensively. TDSOs are expected to control the flexibility of DERs, effectively using the DER management platform with AI in order to manage their grid operation, particularly elimination of grid congestion. There are two fundamental differences between the two models. One is "who actually monitors/controls DERs?". It is the aggregator in the former model and the grid operator in the latter model. The other is that optimization of distribution grid is more focused in the latter model in comparison to the former model.

A demonstration project of this framework has just been launched in 2020 by TEPCO Power Grid (TDSO) and others in the Tokyo area financially supported by METI Japan, but any associated results have not been reported yet. Nevertheless, the DERs management platform is expected to deliver notable benefits. First of all, full utilization of available DERs by grid operators would realize much efficient grid management to minimize grid congestion and to control voltage. Moreover, the DERs management platform is not merely employed by grid operators but also by aggregators as well by providing a system platform and bidding/trading on behalf of aggregators.

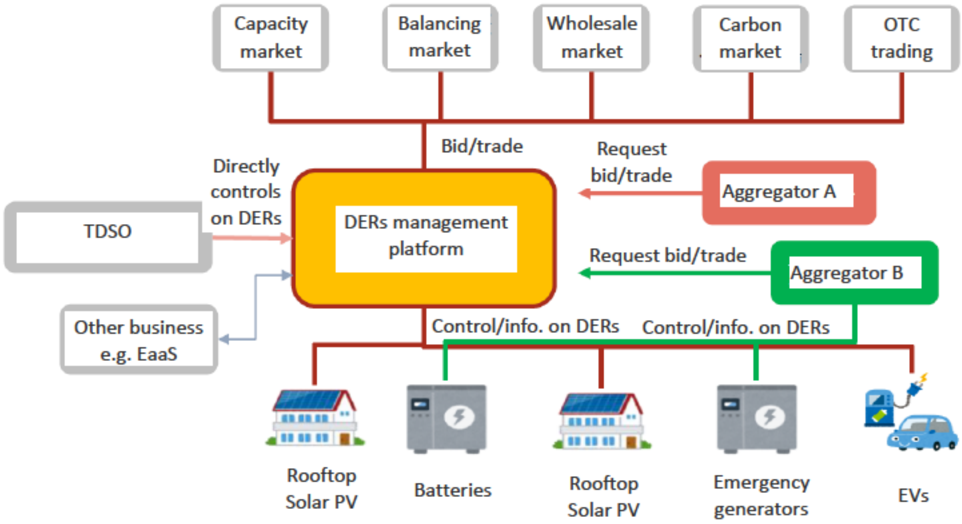

Figure 5: Overview of the DERs management platform model: TDSOs control DERs.
Source: METI (ibid.)

The functions of the DERs management platform can be divided into the following three categories; 1) resources/grid management, 2) resource procurement and 3) resource control/ management. Among them, 1) resources/grid management, which encompasses a comprehensive and intensive monitoring/controlling of DERs connected to distribution grid, is seen as the most crucial function of the platform. These functions of the platform in connection to TDSO, aggregators and DERs and are illustrated in the following figure.

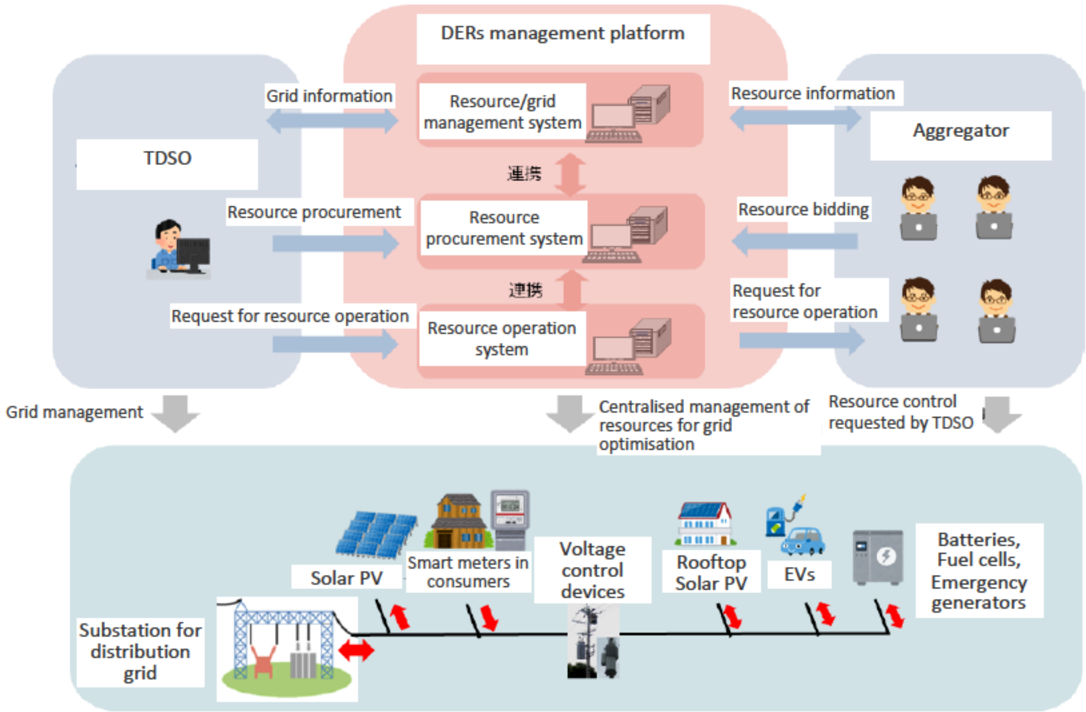

Figure 6: Functions of the DERs management platform.
Source:METI (ibid.)

Regarding the use of digital technologies for the functions of grid and flexibility operation with DERs summarized in Table 4 (in Chapter 2.2), this demonstration project primarily focuses on "control of DERs" by DTSO, followed by "monitoring the status of the grid" and "maintaining grid stability and reliability" which are assumed to be achieved by "control of DERs". Almost all attention is paid to the technical aspects of these functions. On the other hand, the economic aspects such as "optimized market design/ operation" and "billing" seem to be out of scope in this project, at least in this stage. Smart meter is implicitly assumed to be completely rolled out, since its penetration rate in the lower voltage consumers was already 74.1% in March 2019 and planned to be 100% by 2020 at Tokyo area, where the demonstration project is currently conducted.

Apart from this demonstration project and the existing VPP projects, model cases of utilization of DERs with digital technologies for grid operation are not commonly found in Japan. An example can be seen in the case of "improved wind/solar generation forecast", which was identified as one of the key functions needed to avoid congestion/ bottlenecks in Chapter 2. In Japan, this function is currently addressed in a way that geological climate data with higher granularity is used, rather than employing big data collected by IoT embedded into each DER. This is because it is pointed out that too much amount of big data with too much higher granularity from each DER is likely to cause inefficiency and increase forecast error, resulting in inferior forecast output compared to the case using climate data obtained by averaging a certain spatial range. This may represent a typical example seen in the country at which big data collected from DERs is not intended to be fully utilized yet.

3.2 Germany

The German cases mostly draw on the results of demonstration projects within the funding program "Smart Energy Showcase - Digital Agenda for the Energy Transition" (SINTEG) by the Federal Ministry for Economic Affairs and Energy. It comprises five large model regions known as showcases, in which model solutions for the energy supply of the future are developed and demonstrated. The focus of the program is on digitalizing the energy sector. Out of more than 300 projects involved, this study is highlighting those who are offering innovative solutions for the monitoring and maintaining of grid status/smart grids as well as the establishing of regional flexibility markets or platforms using IoT, AI and modelling. Special attention will also be given to the aspect of controlling DERs by DSOs.

3.2.1 Monitoring and maintaining of grid status/smart grids

Enera showcase: Simulation platform for the evaluation of flexibility potentials, development of operating scenarios and future scenarios of the network using real flexibility

Enera is a SINTEG showcase in the Northwest of Germany, with high shares of wind power. The work of the DLR Institute for Networked Energy Systems within the enera project shows how the curtailment of renewable generation plants due to bottlenecks in the grid can be avoided or significantly reduced through the targeted use of flexible energy conversion units. Furthermore, scenarios are included in the work, which also represent the future relevance of flexibility options. A simulation platform for the evaluation of flexibility potentials and the development of operating scenarios serves as a starting point. The results obtained from the platform are based on three core elements: On data and insights from practice; on modeling and adaptation based on real measurement data; and on intensive result validation.

The simulation platform determines the grid-serving flexibility requirements that arise due to critical grid situations - for example, due to the overloading of resources during the transport of wind power during a strong wind front. In these situations, grid operators have so far been able to reduce the output of renewable generation capacities by means of feed-in management ("Einspeisemanagement", short EinsMan) and thus counteract an overload of the grid. Whether or not an overload exists is largely dependent on the current generation or load situation and, in particular, on the topology of the grid. The simulation platform therefore includes not only a detailed model of the high-voltage level of the electrical distribution grid of the enera region, but also extensive models of the energy conversion units that are connected to this grid. The technologies considered in the simulation platform are: wind turbines, electrical storage as large-scale and home storage for photovoltaic systems, power-to-heat for households, power-to-gas with the operating modes "grid-serving" and "full load", and biogas with and without increased nominal power. The models were fed or developed from measurement data of real operating equipment, by means of information provided by cooperation partners, as well as with data from manufacturers and publicly available information sources.

The crucial elements of the simulation platform are:

- Time- and location-resolved quantification of the flexibility demand of the grid due to grid congestion based on the simulation of the vertical grid load

- Determination of the flexibility potential of decentralized energy conversion units for the targeted avoidance of grid bottlenecks
- Inclusion of scenarios for the analysis of the future grid-serving flexibility demand

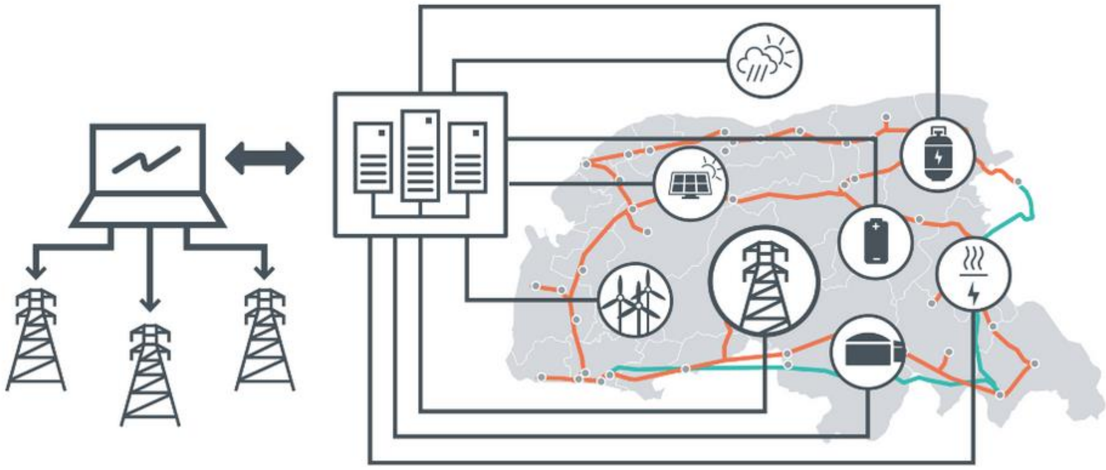

Figure 7: Simulation platform of the enera region in northern Germany.
Source: enera (2020a)

During the development of the platform, special attention was paid to the validation of the simulation so that realistic results can be achieved and subsequently used in practice.

Enera showcase: Short-term network condition forecast by machine learning

Forward-looking network management as a basis for better integration of renewable energy sources and the elimination of congestion requires early and precise forecasting of local network load. Such forecasting is expected to become mandatory for DSOs as part of the redispatch and EinsMan reorganization currently under discussion in Germany. Up to now, there is hardly any experience and established solutions for forecasts at the individual substation transformer level, so that the question for all network operators in Germany is how to best meet a forecast obligation. Based on the experience with flexibility markets in the enera project (see chapter 3.2.3), the DSOs EWE AG and EWE Netz took a closer look at the possibilities for forecasts for this use case and to demonstrate the feasibility of a software module in principle. The expected power values of the decentralized feeders are particularly relevant for the network condition forecast. In addition to the feed-in from wind energy and photovoltaics, the grid load also includes the consumption by connected consumers and connected low-voltage grids as well as other feeders such as combined heat and power plants.

For this project, a data-driven forecasting method for the short-term forecast of the vertical grid load at the MS/HS node has been prototypically implemented and evaluated on the data of four substation transformers. The approach used allows to train a forecast model on the time series data itself, so that a relatively complete picture of the vertical network load can be generated.

In summary, it was successfully demonstrated that forecasting by machine learning is possible independent of grid topology and knowledge of the underlying generation structure, and that such a software module can be well applied to different situations. Regardless of the feasibility of the model and the forecast quality achieved, the implementation of a software module would also require integration into an ecosystem at DSOs and hardening of the algorithm for all special cases. If the need for improved forecasts and the avoidance of congestion through the current redesign of redispatch also brings a financial incentive, self-learning forecasting methods can provide significant added value for improving forecast quality as well as for widespread deployment regardless of the exact circumstances (enera 2020b).

Enera showcase: Network-optimizing distribution network automation

As part of the enera research project, Phoenix Contact Energy Automation GmbH demonstrated solutions for distributed, decentralized and partially autonomous grid automation in distribution grids. The self-sufficient automation concept can react independently to critical network situations and control them safely via targeted network interventions. Manual intervention by the utility grid operator is thus no longer necessary.

The demonstrated overall concept of network-optimizing distribution network automation is divided into the two core components of 1) monitoring and 2) control of the network status.

Within the scope of monitoring, the existing network condition is continuously monitored and evaluated. The network status includes on the one hand the network topology, which results from the current switching state of the distribution network, and on the other hand the evaluation of measured values of the measuring points distributed in the network. The monitoring component is called upon and executed continuously. The cyclic call ensures a dynamic update of process values and evaluation results, which forms the basis for the functionality of the network control. With the status information and evaluation results of the monitoring component, the controller component can trigger active network interventions to remedy network status violations in the monitored distribution network area. It is particularly important to correctly identify the specific use cases and to initiate the appropriate and target-oriented measures in each case. Here, controllable systems (e.g., renewable energy generation systems) are used as actuators in the sense of grid-serving management.

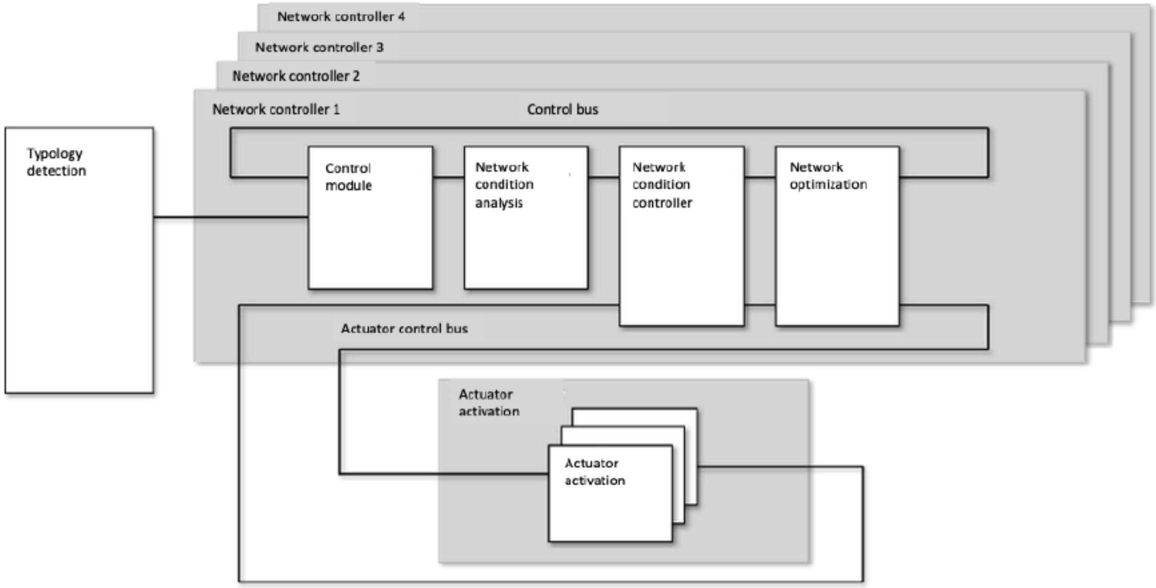

Figure 8: System architecture of the network-optimizing distribution network automation.
Source: enera (2020c)

Other examples

Project	Project content
AI4Grids	o AI-based planning and operational management of distribution grids and microgrids for optimal integration of renewable energy generators and fluctuating loads o Digital Grid Lab of Fraunhofer ISE will carry out real-time simulations, since the local generation and consumption structure and thus a network state that is as real as possible can be mapped here o In real-world laboratories in Friedrichshafen and at the university of Constance, practical tests will be carried out to determine whether the AI system and its components provide added value for the power grid at both building and neighborhood level o For further information see: https://www.ise.fraunhofer.de/de/presse-und-medien/news/2020/projekt-ai4grids-kuenstliche-intelligenz-fuer-stabile-stromnetze.html
Intelligent Grid Platform (IGP)	o The Intelligent Grid Platform (IGP) is a modular software assistance system that can be used to digitize and automate network planning and network operation management processes for distribution network operators o A total of 12 customized applications are available for this purpose in the three main application areas of data quality, network planning and operations management o The IGP is already a commercial offer which is provided to DSOs by the company envelio o For further information see: https://envelio.de/intelligent-grid-platform/

3.2.2 Controlling of DERs by DSOs

Windnode showcase: targeted use of decentralized generation plants

For a more flexible provision of reactive power from the distribution grid, the creation of control options for wind and PV plants is necessary. The Windnode project of the DSO WEMAG Grid deals with the implementation of such a control, directly from the control system. This is to be used to respond to current requirements from the distribution or transmission grid. These requirements also include the provision of reactive power quantities at a specified interconnection point. In addition, work is being done to ensure that defined target voltages are stabilized directly by automatically provided reactive power.

An essential component of the project is the functional expansion of the network control system to include the so-called intelligent reactive power management system (IBMS), the functional scope of which includes the telecontrol integration of the generation plant, the calculation of node-specific reactive power potentials, the transmission of direct reactive power control commands (setpoint specifications) on request from the distribution or transmission grid, and the visualization of the control potentials.

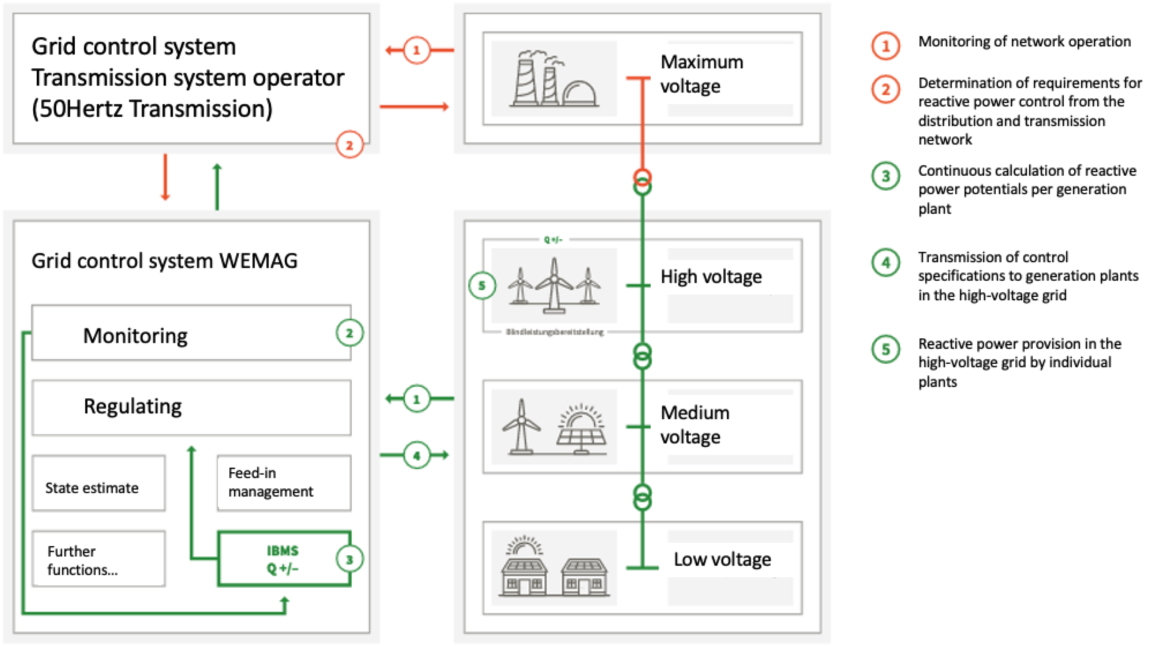

Figure 9: Sequence of the process in the Intelligent Reactive Power Management System (IBMS) in WEMAG's network control system.
Source: Windnode (2020, p. 92)

In order for generation plants to participate in the reactive power control of the IBMS, a prequalification is required. The plant pool is currently being expanded through intensive testing of possible generators. By the end of the project, all generation plants connected to the high-voltage grid level of the DSO WEMAG Grid are to be included in the system in order to exploit the maximum control potential from the distribution grid. Due to the focus of the project on the targeted use of decentralized generation plants in the distribution grid, the transmission grid is not addressed.

Windnode showcase: targeted use of decentralized generation plants

Bosch.IO and devolo are working on solutions that allow barrier-free integration of smart home solutions, heat pumps and PV inverters into the existing smart grid concept. In the process, the Windnode partners developed an initial solution approach that makes it possible to create a regulatory penetration of the energy supply companies into home automation. In this way, private flexibilities, such as controllable loads and energy storage, can be offered to interested market players.

The narrow regulatory limits for communication via a German smart meter gateway (SMGW) require an expansion of the solutions established in the Internet of Things (IoT) environment. Currently, access via the SMGW to the home network of an end consumer is only possible via the so-called controllable local systems interface (CLS interface). The current evolutionary stage of the German smart grid essentially allows only two regulatory permissible ways to communicate with customer hardware. On the one hand, protocol conversion or encapsulation of non-smart grid protocols using a virtual or real control box. On the other hand, a natively supported protocol such as http as the communication carrier. Both approaches were rigorously pursued and tested in the visitable sites and laboratory demonstrations. Using the existing smart grid technology, the communication via the CLS channel of the SMGW turned out to be the most barrier-free for the involved partners.

In the first stage, the bridge between smart grid and smart home was built directly via the "Highly Secure Communication Scenario 4" (HKS4) defined by the Federal Office for Information Security for the smart meter gateway: in this scenario, an external market participant (EMP) initiates a secure channel from the EMP via the SMGW to a device in the CLS network. The practical implementation for the customer is that a network-capable device is connected directly via the CLS network socket of the SMGW. The necessary gateway administrator and energy manager solution as an external market participant was implemented by Bosch.IO. To control the customer hardware, devolo implemented a management interface on the Smart Home Control Box. In the test, several loads could be successfully controlled and their consumption measured individually and to the second. An interesting challenge was the implementation of the HKS4 case according to requirements, as this had not yet been tested much in the field. After successful commissioning, however, this was achieved reliably and smoothly.

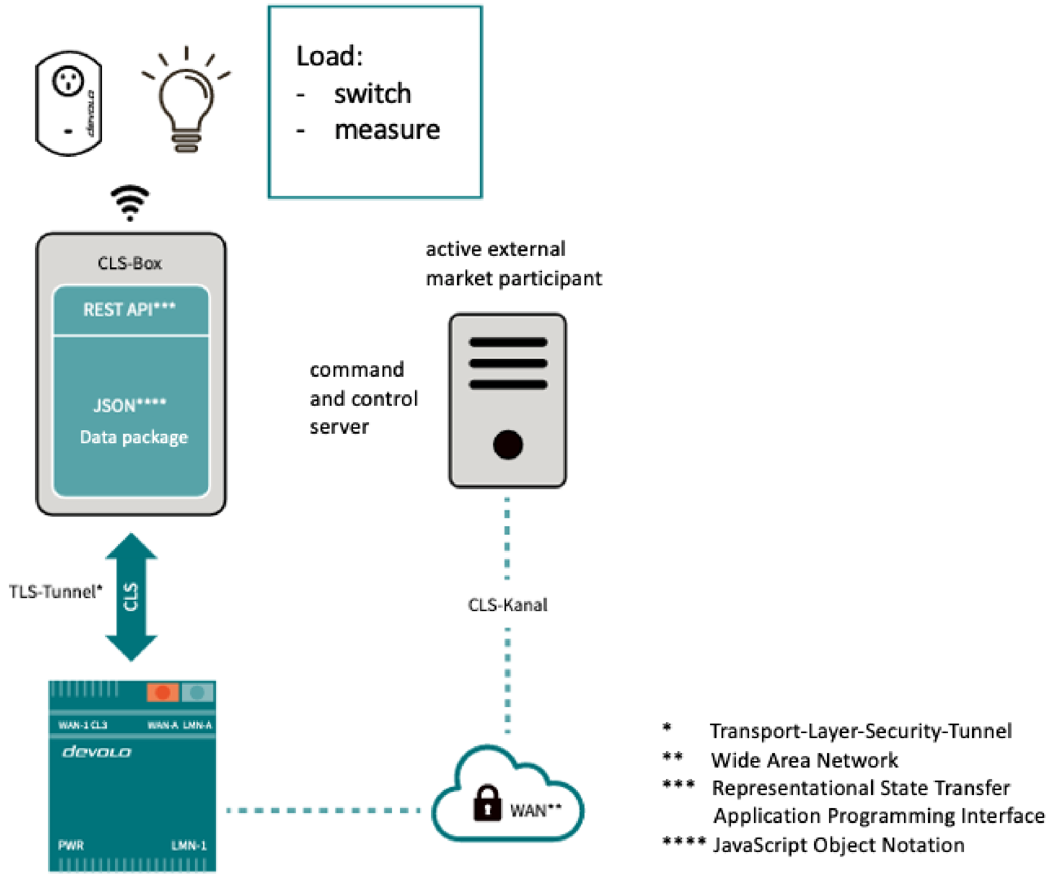

Figure 10: Access to smart home devices within the regulatory framework via SMGW and CLS tunnel: Small-scale flexibilities and load management via control server of an active external market participant.
Source: Windnode (2020, p. 113)

Another potential added value for customers would be a dedicated IoT-specific interface. In the current form of the SMGW, however, this solution approach is not feasible due to the current regulatory framework conditions. Looking to the future, a solution would be desirable that allows smart home hardware, wallboxes, heat pumps, PV systems or other customer hardware to be connected directly and configuration-free to the SMGW without any additional hardware. Here, direct support of already established IoT protocols on the SMGW would offer ready and available solutions. The customer could then not only obtain information about his or her consumption values centrally, as provided for in the transparency and display software (TRuDI), but would also have an overview of meter values and the status of his or her own hardware via a user interface.

Other examples

Project	Project content
Enera showcase **Einspeisevisualisierungsapp** **("Feed-in visualization app")**	o Feed-in visualization app for prosumer households: the generation output of the in-house PV system and household electricity consumption are displayed and offset live and in historical curves o The resulting recommendations for action enable users to optimize their consumption behavior to the current and forecast future in-house production o The smart readout and communication module developed in the enera project collects the required measurement data at the PV generation meter and the grid transfer meter of the test household o For further information see: https://projekt-enera.de/blog/einspeisevisualisierungsapp-eivi/
Enera showcase **Automation of the feed-in management of RES**	o Automation of the feed-in management of RES in real time carried out by a grid controller o Laboratory phase and field test of partially automated grid operation has been conducted o For further information see: https://projekt-enera.de/blog/teilautomatisierter-netzbetrieb/
Enera showcase **New busines models based on aggregated flexibility**	o New business models based on the aggregated flexibility of micro plants o Role of the aggregator of micro plants can be taken over either by the manufacturer of the plants or as a service by VPP o For further information see: https://projekt-enera.de/blog/eroeffnung-neuer-vermarktungspotenziale-fuer-aggregatoren-von-kleinstanlagen/
Windnode showcase **"StromPager DX"**	o As part of Windnode, a control technology for low voltage was further developed and tested in the real-world laboratory - the "StromPager DX" o A first level of coordination function has been created at the operational level. This enables any authorized market partner to send control commands without having to operate a certified control system as an active external market participant (EMT) o Hybrid solution of smart metering system and secure broadcast thus also fulfills the door function for value-added services via the future smart meter gateway infrastructure o For further information see p. 114f.: https://www.windnode.de/fileadmin/Daten/Downloads/Jahrbuch/WindNODE_Jahrbuch_2020_Web_150dpi.pdf

3.2.3 Regional flexibility markets and platforms

Enera showcase: enera Flexmarket and marketplace

At present, network operators mainly use non-market measures prescribed by law to eliminate congestion. In addition to cost-neutral measures, such as switching measures, these are primarily redispatch and feed-in management measures. In order to proactively avoid grid bottlenecks, thus relieving the grids and being able to accommodate further renewable energies in the grid, it is necessary to develop additional local flexibilities for congestion management. Through digitalization and new technical possibilities, this demand is then also met by suppliers who, as active participants in the energy system, can provide this local flexibility with their generation and consumption plants as well as storage facilities. Previously, however, there was no environment in which grid operators could make efficient use of precisely these opportunities. In the SINTEG project enera, the exchange-organized enera flexibility market (enera Flexmarkt for short) was developed and demonstrated for this purpose. It should be noted that this is not yet generally allowed in Germany, but it was allowed as a regulatory experiment in the SINTEG projects. Furthermore, EPEX SPOT designed, developed, implemented and operated the enera marketplace, building on the market design for the enera Flexmarket. The demonstration phase of the flexibility market concept as a whole and the marketplace in particular was successfully conducted from February 04, 2019 to June 30, 2020. During the demonstration phase, six flexibility providers, two DSOs and one TSO operated safely and efficiently in the market, with over 4,000 orders sent and 130 calls completed.

Elements of the enera Flexmarket

Local market areas form the lowest granularity in the enera Flexmarket and comprise network topological regions in which the connected flexible plants act with the same or at least approximately the same sensitivity to all potential congestion. Accordingly, the local market areas are to be selected in such a way that no congestion exists in the corresponding region for any of the network operators. The assignment to market areas makes the flexibilities comparable in their congestion effectiveness and adds a local component to the offers - which is missing on the wholesale market. With the simultaneous **standardization of flexibility products**, flexibility offers also become comparable in price. Automatic comparison and automatic contract execution thus become possible, which significantly increases the efficiency of such a small-scale market. In order to create a high level of acceptance here and thus achieve liquidity on the platform, which is crucial for the success of the market, the **barriers to market entry should be kept as low as possible**. This was achieved in the enera project by basing the market design and the processes required for implementation on the existing wholesale processes for intraday trading of electricity. In addition, in order to be able to use the **greatest possible flexibility potential** for congestion management, the market design should take into account, as far as possible, all generation plants, storage facilities and consumers that can provide a planned deviation from their original, purely market-based schedule. This includes generation plants, regardless of output and whether they are conventional or renewable generation plants. Storage facilities, where at least the charging or discharging process can be influenced, can also be included, as can be consumers (enera 2020d).

The trading process on the enera marketplace

Trading on the enera market opens at 3 p.m. of the previous day (D-1) and ends 5 minutes before delivery starts. This allows flexibility trading until shortly before delivery, which is especially important due to changing forecasts. Analogous to the intraday market, continuous trading is possible on the enera market. In practice, however, the network operators only become active in the market when a bottleneck is expected. They are able to buy renewable and non-renewable flexibility, offered for different delivery times and different delivery periods (15 minutes and 60 minutes).

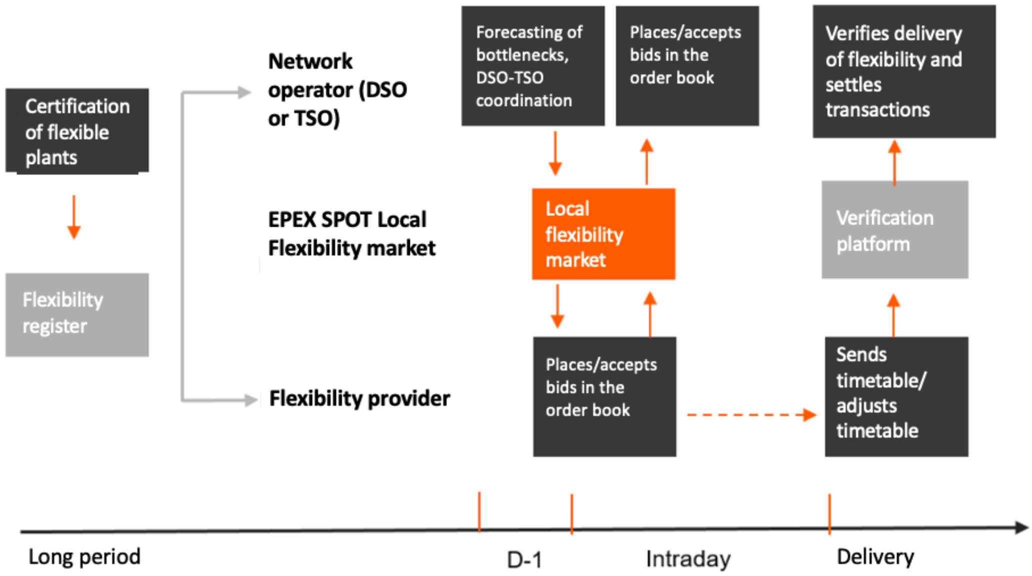

Figure 11: The enera market over time in the short-term markets, source: EPEX SPOT (enera 2020e)

The functioning of the local flexibility market displayed in Figure 11 can be explained as following:

- At the beginning, the **connecting network operator** issues a one-time certification for the flexibility plants, which serves as an authorization to participate in the flex market
- The **network operators** regularly carry out network congestion forecasts in order to detect congestion in their network as early as possible in the intraday time range and to determine the resulting flexibility demand, as well as to coordinate this with the other network operators. The network operators then post their flexibility requirements and their willingness to pay on the trading platform.
- Similarly, **marketers** post their available flexibility as well as offer prices.
- The **trading platform** compares supply and demand and subsequently informs the market participants if both bids are compatible and a transaction has been concluded. Order matching rules ensure that orders are executed at the best price available in the system.
- Subsequently, the **flexibility provider** is obliged to deliver the flexibility according to the product specifications.
- Flexibility delivery has a physical impact on the power grid (injecting or withdrawing power to or from the grid), effectively resolving or mitigating grid congestion. This flexibility provision is verified ex-post by grid operators based on metering data at the point of entry as part of the verification platform processes.

The transmission of schedules and the measurement of actual values can be used to detect undesirable behavior, especially in the form of increase-decrease (inc-dec) gaming. Inc-dec gaming in general is the activity of traders to strategically position themselves in the spot market in anticipation of a redispatch market in order to maximize their overall revenues. Within the scope of the project, market monitoring in combination with appropriate market rules that include corresponding sanction options was developed as a concept for avoiding strategic behavior in the enera flex market (enera 2020f).

The trading system used for the enera marketplace is the M7 trading system, provided by the German stock exchange (Deutsche Börse AG) and already known from the intraday trading of EPEX SPOT. This trading system has been extended with new functionalities and features to reflect the use case of a flexibility market.

Enera showcase: Network operator coordination process

In the run-up to each market use of the enera marketplace, network operator coordination with the respective downstream network operators takes place to ensure efficient and effective use of market-procured flexibility and secure and reliable electricity network operation. Since upstream network operators (e.g. TSOs) do not know the network status of the respective downstream network operators (e.g. DSOs), without coordination there is a risk that an upstream network operator will cause congestion in the downstream network through uncoordinated measures.

The placement of a purchase order or bid on the market platform by a network operator requires the approval of all downstream network operators. It is the task of the respective network operator to obtain approval from the downstream network operators. The network operator willing to contract shall send its request for market use to the network operator directly downstream of it in a jointly defined data format. This request must be received by the respective downstream network operator no later than thirty minutes before market use and no earlier than six hours before the end of the provision of flexibility. In deviation from this, the request must be received by the downstream network operator only 15 minutes before market use if only one downstream network operator is involved in the process. In addition to the time period, the request must contain at least information on the market area(s) in which the upstream network operator wishes to acquire flexibility as well as the forecast quantity of flexibility in MW per 15-minute interval.

The downstream network operator shall calculate any capacity restrictions and notify the upstream network operator thereof. The capacity restriction corresponds to the usable capacity bands that may not be exceeded by the upstream network operator as a result of market usage. By notifying the upstream network operator, the downstream network operator grants the necessary release for the flexibility call for the notified volume. If, as a result of the request, a market area of a further downstream network operator comes into question for a potential flexibility provision, the requested network operator in turn requests in advance any restrictions of the further downstream network operator.

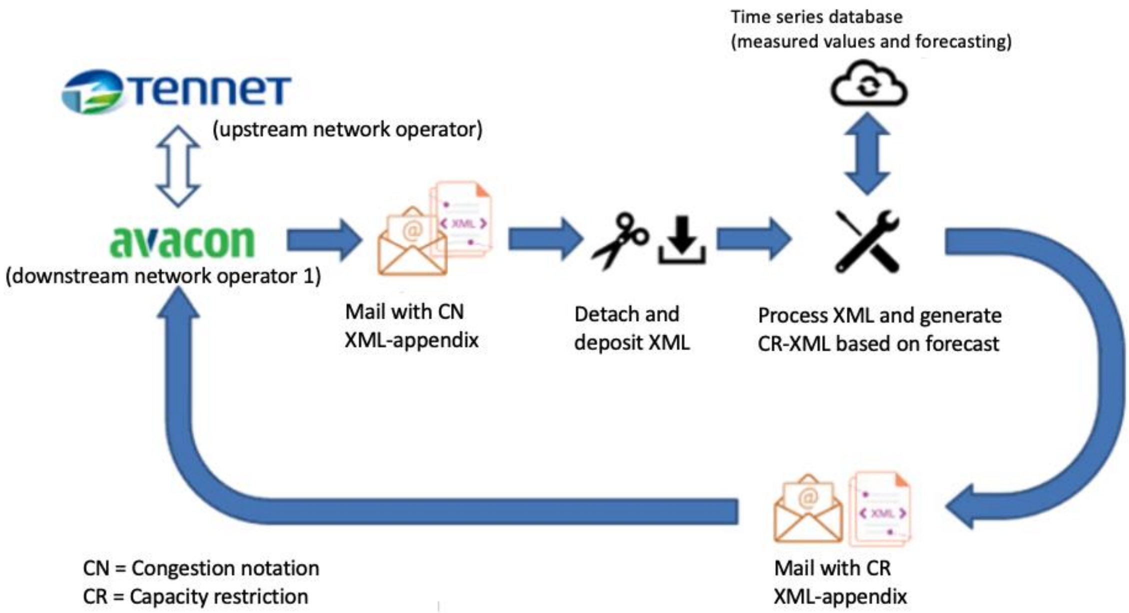

Figure 12: Process flow at EWE Netz (downstream network operator 2).
Source: enera (2020g)

Enera showcase: Implementation of an Active Network Management

In cooperation with the DSO EWE Netz GmbH, the conception and implementation of the interface for the generation of files with flexibility demand for the enera market interface were carried out for medium-voltage areas of the enera region and verified in a field test. The feed-in and load forecasts were provided by the consortium partner energy & meteo systems GmbH.

Figure 12 summarizes the functionality of the Active Network Management (ANM) for the implementation of the so-called yellow traffic light phase in the forecast mode. Schedules and forecasts from external data source are fed into the ANM via the interface applications. The ANM calculates the state estimate and determines the traffic light. The subsequently calculated optimization uses the control variables allowed for the traffic light phase. When the traffic light phase is yellow, a flexibility demand is calculated. This flexibility demand is forwarded to an external market interface via an appropriate ANM interface. There it can be converted into a flexibility request to the regional flexibility market (as described above). The activities on the market are included as a result in the schedules of the flexible plants and are transmitted to the ANM via a corresponding interface. This closes the circle.

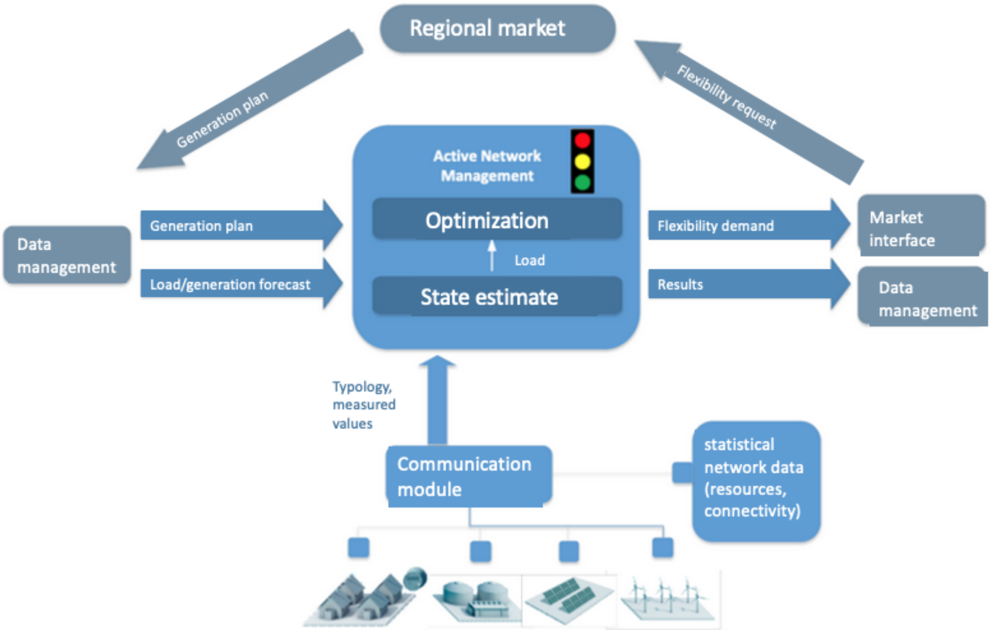

Figure 13: The functioning of the Active Network Management (ANM).
Source: enera (2020h)

The laboratory test and installation of the Active Network Management (ANM) was carried out in the network control center at EWE NETZ. Among other things, the field test showed that the application of Demand Response at the distribution network level is technically feasible in principle. However, the following factors, among others, are indispensable for successful operation:

- A sufficient amount of flexibility (especially flexible load) in the distribution grid. The ANM can be used to determine the required amount. The availability of flexibility not only allows for the elimination of congestion, but is a necessary condition for market liquidity.
- Reliable load and feed-in forecasts, from which one can accurately derive the time, level as well as duration of the bottleneck.

Designnetz showcase: PolyEnergyNet

The SINTEG project Designnetz maps the power grid into local and regional energy areas. As far as possible, energy should be consumed or stored where it was generated. Local energy sectors can exchange with each other via regional connections.

For example, Stadtwerke Saarlouis is developing a resilient local network consisting of autonomous sub-networks, so-called "holons". The subnetworks are not static. They adapt dynamically to the respective network situation and reorganize among themselves in order to always guarantee the optimal supply situation. The electricity, water and gas networks were coupled with a fiber optic network to control the holons. Electricity generated by local photovoltaic systems, for example, can be intelligently controlled and converted into heat energy in a power-to-heat plant to stabilize the grid. This avoids high transmission losses and prevents voltage band problems. Sector coupling creates an overall efficient polygrid, the so-called PolyEnergyNet.

In order to realize the holons, the project partners developed various systems that enable the operation of autonomous subnetworks in a critical network infrastructure. These include holon management as decentralized intelligence, integrated measurement concepts, real-time data management, actual-state detection, forecasting procedures, and the associated protocols for overall control. Attack and anomaly detection continuously monitors the ICT network, detects attacks and faults, classifies them and initiates appropriate countermeasures.

This way, PolyEnergyNet has developed a new paradigm for the control of the energy system with the 'holar model'. Previous models envision a rigid, hierarchical or tree-like structure. The holar model, on the other hand, is dynamic. Depending on demand, the 'holar elements', i.e. the generators, consumers, storage units and line elements, rearrange themselves into self-controlling groups, the 'holons'.

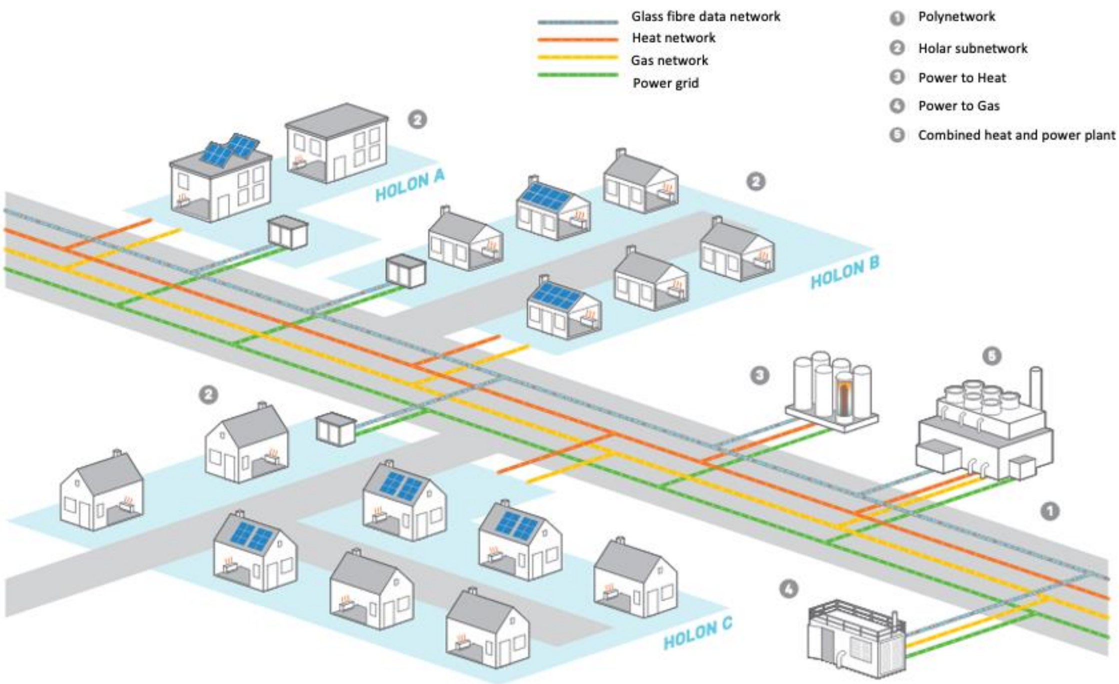

Figure 14: The PolyEnergyNet.
Source: Designnetz (2020, p. 17f.)

Windnode showcase: Uckermark integrated power plant

The „Uckermark integrated power plant" demonstrates how the coupling of renewable generation plants, storage facilities and PtX plants can completely replace the functions of conventional power plants in the future. A feed-in grid with a radius of 25 kilometers connects wind energy, photovoltaic and biogas plants, a 20 megawatt battery, a heat storage tank with 1,000 m^3, and a hydrogen electrolyzer.

All components of the integrated power plant are already directly connected to each other electrically and digitally and are coordinated with each other. By connecting all plants, the decentralized and heterogeneous structures are unified with the help of the IT platform ENERTRAG PowerSystem. The platform monitors and controls all individual plants in the integrated power plant and groups them into large power generation units. The goal of the Windnode project partners was to advance the coupling of the interconnected power plant and make it even more secure against external attacks. Due to the rapid technological development of wind turbines, the technical software requirements for the regulation and control of turbines have also changed significantly. With the support of Windnode, ENERTRAG PowerSystem was therefore further developed as a program that is designed for the formation of renewable power plants and is thus ideally suited for monitoring and controlling the large number of directly coupled plants of the interconnected power plant.

Other examples

Project	Content
Enera showcase: Municipal web application	o Municipal web application visualizes in real time the electricity consumption of numerous properties in the model region o The current consumption of a property could be compared at any time with the values of the previous week or month and thus irregularities, caused for example by a defective terminal device, could be identified quickly and easily. o For further information see: https://projekt-enera.de/blog/mit-digitalen-loesungen-zur-kommunalen-energiewende/
NEW 4.0 showcase: ENKO	o The digital flexibility platform ENKO makes it possible to use more green power in the model region and at the same time relieve the power grid o The project comprises the entire development of the digital flexibility platform called "ENKO- ENergie intelligent KOordinieren" ("coordinate energy intelligently"), on which plant operators can offer their flexible loads to grid operators. In addition, innovative algorithms were developed for the forecast of flexibility requirements by the grid operator and continuously improved in live operation. o For further information see: https://new4-0.erneuerbare-energien-hamburg.de/de/new-40-projekte/details/ENKO-konzept-zur-verbesserten-Integration-von-Gruenstrom.html

4 Discussion of use cases and business/market models identified

In this chapter, we compare Table 5 on use cases and business/market models in chapter 2.3 to the use cases identified chapter 3. In this way, we can conclude which business/market models are already established or starting to be established on commercial basis and which are in development or demonstration phase only, and the reasons why (lack of technologies or markets/regulation /business cases).

For the establishment of a smart grid, firstly **optimized demand and supply forecasts** are absolutely necessary. As shown in Table 5, according roles of actors in relation to business/market models for these functions are: consumers optimizing their bills; TSOs, DSOs forecasting grid status and maintaining stability and reliability; TSOs for the reserve control market; aggregators optimizing the use of generators and flexibilities; generators optimizing their generation and maximizing their revenues/profits; suppliers optimizing their purchasing portfolio and their balancing group. For many of these business/market models, forecasting is well developed; for example, its use by aggregators such as Virtual Power Plants was discussed in our previous study (Ninomiya et al. 2019). It has also been demonstrated for the function most relevant for this study, i.e. TSOs, DSOs forecasting grid status and maintaining stability and reliability. As described in chapter 3, for example, a simulation platform for the evaluation of flexibility potentials, development of operating scenarios and future scenarios of the network using real flexibility was developed within the enera project region. This is also one aim of the demonstration project currently developed in Japan and described in the previous chapter.

For similar projects in other regions, special attention has to be paid to the validation of the simulation so that realistic results can be achieved and subsequently used in practice. They are then ready to become a (part of) a business model, in which the TSO or DSO monitor the grid status and use grid resources and EinsMan for maintaining grid stability and reliability. However, for enabling the full use of DERs for this purpose, the regulatory environment for using DERs would need to be created or improved in Germany and Japan (see below).

Secondly, the **monitoring of grid status and the forecast of (near) critical status** needs to be advanced as well. As shown in Table 5, TSOs and DSOs forecasting grid status and maintaining stability and reliability are necessary users for this function. As described in chapter 3, for example, the enera project demonstrated a solution for distributed, decentralized and partially autonomous grid automation in distribution grids. Also, a short-term network condition forecast by machine learning was developed and demonstrated within the project framework. In the demonstration project in Japan, monitoring of grid status is viewed as a part of grid management, which can be performed by control of DERs described below. Regardless of the feasibility of the model and the forecast quality achieved, there are still technical and regulatory issues to be solved. The implementation of a software module would also require integration into an ecosystem at DSOs and hardening of the algorithm for all special cases. Also, the current redesign of redispatch needs to bring a financial incentive for improved forecasts and the avoidance of congestion. Despite this need, the example of the Intelligent Grid Platform (IGP) demonstrates that there is already a market in Germany for commercial offers like this one.

As a third function, the **use and control of DERs** for flexibility needs to be advanced. As shown in Table 5, the respective roles of actors in relation to business/market models for the use/control of DERs are: DER owners maximizing their revenues/profits; aggregators maximizing their revenues/profits; DSOs or TSOs using DERs for grid stabilization if they have direct control. For example, as described in chapter 3, the Windnode project of the DSO WEMAG Grid deals with the creation of control options for wind and PV plants directly from the control system. In order for generation plants to participate in the reactive power control, prequalification in the form of intensive testing of generators is required. That is why the project is still in the development phase. Furthermore, Windnode partners developed an initial solution approach that makes it possible to create a penetration of the energy supply companies into home automation for control purposes. However, this project is also in the testing phase. To make use of this solution approach on a big scale, an adaption in regulatory framework conditions of the SMGW would be needed. In general, for enabling the full use of DERs for maintaining grid stability and reliability, the **regulatory environment** for using DERs would need to be created or improved in Germany.

In the Japanese demonstration project, use/control of DERs is considered as the most important feature of the model with which DTSOs are expected to conduct effective grid management. In Japan, although the demonstration project has just been initiated, full use of DERs as flexibility resources by grid operators also requires reform of the existing regulatory framework (see below).

As shown in Table 5, roles of actors in relation to business/market models for the function of **optimized market design and operation** are: operators entitled or accredited to create and operate a market, e.g. private electricity exchanges; TSOs for reserve control markets and DSOs for regional flexibility markets. As an example, in the enera project, the exchange-organized enera Flexmarkt was developed. It demonstrated how suppliers with their generation and consumption plants as well as storage facilities can provide local flexibility to TSOs and DSOs. Within the Flexmarkt context, a network operator coordination process and an Active Network Management was developed as well. However, it should be noted that to realise a flexibility market with such features on a commercial basis, the regulatory framework would need adaptation. Within the project Designetz, Stadtwerke Saarlouis are working on a resilient local network consisting of autonomous sub-networks, so-called "holons". The approach is still in development phase. Within the Windnode project, the „Uckermark integrated power plant" connects different forms of DERs and storage options on a regional scale. However, possible business models for the operation are still under research. In the Japan, optimized market design is somewhat out of consideration since almost all attention is solely paid to the technical aspects of the DERs management platform system. This does not necessarily mean that the market aspect is seen as unimportant, but it would need to be investigated after overcoming the technical challenges.

Further roles of actors in relation to business/market models for **smart metering, offer and selection or activation of flexibilities, and billing** are: Smart meter operators; market operators; flexible DER owners (offer in markets; activate if not done automatically, or if they self-select in response to incentives from DSOs) and suppliers, market operators, aggregators, DER owners. Due to the focus on monitoring and maintaining of grid status/smart grids, controlling of DERs by DSOs and regional flexibility markets and platforms, use cases in chapter 3 didn’t draw extensively on these functions/business models.

5 Recommendations on policies and regulations

5.1 Recommendations for Japan

As already mentioned, in Japan, the demonstration project with the DERs management platform associated with a range of digital technologies conducting centralized management of DERs by DTSOs for optimization of distribution grid has just been initiated and, to date, no tangible results have been reported. Despite it may be premature to suggest recommendations on policy and regulation at this stage, the discussion based upon the experiences in Germany, which is clearly ahead of Japan in this field, provides valuable policy implications which could be applied to Japan in the similar manner.

Currently, the main concern of the demonstration project extensively focuses on the technical aspects of the functions of the DERs management platform. In other words, the economic aspects, such as the regulatory environment for utilizing DERs via price and realization of local/regional flexibility markets, are currently out of the scope of the project. However, it should be stressed that the Germany's experiences highlight the importance of consideration on such economic aspects of utilization of DERs. Therefore, it is recommended that, in parallel to the implementation of the demonstration project mainly focusing on the technical elements, the regulatory environment should also be carefully considered with the views of how to create economic incentives to utilize DERs for DER owners, DTSOs/DSOs and aggregators and how and what markets, local/regional markets in the cases in Germany should be established and in which regulatory framework. These are still left for further examination.

In a similar context, the experiences in Germany also indicate that a reform of the existing regulatory framework is also necessary in Japan for full use of DERs as flexibility resources by grid operators. Some of the issues were already recognized by the policy makers who recently amended the existing regulations on, for instance, legalization of independent local DSO and aggregators under the electricity industry law, deregulation of the existing measurement law on metering of DERs and an amendment of the grid delivery charge for using the grid. The last one includes a newly introduction of a revenue-cap regulation on TDSO to promote cost-effective grid management. These amendments will be in effect in April 2022, conceivably improving the environment for effective use of DERs.

5.2 Recommendations for Germany

It was shown above that for enabling the full use of DERs for maintaining grid stability and reliability, the regulatory environment for using DERs would need to be created or improved in Germany. However, in this respect, more analysis and testing will be needed to determine, whether the use and control of DERs should be implemented 1) via price signals (e.g. via a shorter-term/interval intraday market plus incentives for control to support the grid), and then a) via control by DER owners, or b) via control by the DSO? Or will 2) a control by DSOs be necessary only in cases of a need to avoid congestion, e.g., via a local/regional flexibility market?

To realise a flexibility market, in which suppliers, with their generation and consumption plants and storage facilities, can provide local flexibility to TSOs and DSOs on a commercial basis, the regulatory framework would need adaptation as well.

Furthermore, it needs to be investigated at which scale the optimization of the grid should happen, e.g., very small cells or holons, or regions of cities and surrounding countryside, or the whole area of a DSO. Also and as a more general note, it is still unclear whether a balance at DSO grid or sub-network level can be maintained, or how much additional use of TSO grid will be needed/optimal. Future regulations can then build on further insights on these topics.

For example, the SINTEG project C/sells recommends the following steps for promoting, testing and using flexibility and digitalization as enablers of the energy transition, not only but including for serving grid stability (C/sells 2020):

- Simplify market access for small plants and open up new opportunities for action (for example, energy exchange in the neighborhood, autonomously acting self-suppliers and RES communities, but also use in grid congestion management via unbureaucratic participation in the flex platforms)
- Design the system of levies, charges and fees in such a way that a systemically reasonable, interference-free integration of flexibility is made possible and that neither the grid operators nor the flexibility providers incur additional costs for a grid-serving use of flexibility, but rather that incentives are created for grid-serving behavior
- Commission area-wide flexibility potential and feasibility analysis and a further roadmap to finally cover all DSO areas in Germany.

Furthermore, it is recommended to develop the standardization of interfaces and processes as well as labels for smart, sustainable buildings and factories with a standardized smart grids interface. For the flexibility proving plant, digital interfaces must be defined that enable control without relays, thus making the gateways a safe communication and control component.

6 Conclusions and further research needs

This paper has focused on the use of digitalization for the optimization of distribution and transmission grids operation to avoid congestion and bottlenecks, utilizing AI and big data collected from DERs with IoT devices. The examination of the functions of grid and flexibility operation needed to avoid congestion/bottlenecks showed that these functions are well defined conceptually. It was also found that each of the functions identified can be associated with the recent development of digital technologies, namely the IoT and AI with big data. The importance of these functions with the digital technologies are highlighted by the recent rapid increase in VRE and DERs in both countries Germany and Japan.

Over all, it can be concluded that the concept of the functions and the associated digital technologies are properly defined and developed at least as seen from the technical view point, although the standardization of software and interfaces for easy-to-use control of especially small DERs and its mass roll-out will need further development. For example, vehicle-to-grid technologies are not yet available in Germany on a broad scale. The roles of actors and their potential business models corresponding to the functions of grid and flexibility operation also adequately identified, proving that uses of digital technologies for the functions by each actor are almost ready to be set at the demonstration projects in the both countries.

The demonstration projects in Germany over the past, particularly the SINTEG showcase program, have developed and tested in principle all the technical and economic solutions needed. Some are already commercially available, while others still need to become easier to apply or more standardized and secure before mass roll-out. However, the most important barrier is the lack of a regulatory environment that would allow DSOs, DER owners, and aggregators to make full use of DERs for optimizing the grid, in addition to the general energy and reserve control markets. Considerable research has been made in policy and regulatory options, but policy still needs to conclude on the best solution between implementation via price signals to DER owners or a local/regional flexibility market. The currently discussed option for DSOs to limit charging power to BEV at times of local grid bottlenecks may only be a first partial and not very smart solution.

In addition, as stated in chapter 5, more research, development and testing is needed to understand at which level a balance between supply and demand while avoiding grid congestions can be achieved, e.g., for very small cells or holons, or regions of cities and surrounding countryside, or the whole area of a DSO. An analysis of area-wide flexibility potential and feasibility seems needed for as many regions as possible.

In comparison to Germany, far less progress has been made in this field in Japan. To date, only one demonstration project has just started and no tangible outcome has been reported. The project is aimed at centralized management of DERs by TDSOs via the DERs management platform employing a range of digital technologies for optimization of grids, particularly elimination of congestion of distribution grids. It was revealed that the focus of the demonstration project is intensively on the technical aspects of the platform system, specifically accurate monitoring and secure controlling of the DERs by TDSOs via the platform. In contrast, the economic aspects, such as the regulatory environment for utilizing DERs via price signals and/or realization of local/regional flexibility markets, are currently out of the scope of the project. However, the extensive experiences in Germany in the implementation of a number of demonstration projects over the past years clearly indicate that profound consideration of these economic aspects is absolutely essential ensuring the project is commercially viable. It is worth recalling that, in Germany, the most significant barrier was identified as the lack of a regulatory environment. It was also emphasized that, once again based upon the experience in Germany, a reform of the existing regulatory framework is also necessary in Japan for full use of DERs as flexibility resources by grid operators. While some of the amendments of the existing regulations have been adopted in 2020 so that independent local DSOs and aggregators will be legalized under the electricity industry law after 2022, further examination for regulatory reform will be needed.

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付録３. CCUS や水素を活用したエネルギー多消費産業の脱炭素化

CCUS and Hydrogen Contributing to Decarbonization of Energy-intensive Industries

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Content

1 Introduction

Hydrogen and carbon capture technologies have been gaining increasing attention as decarbonization options for different sectors of the basic materials industry. Since the production of basic materials is responsible for substantial greenhouse gas emissions in Germany and Japan, this study looks systematically at the role these technologies could play for industry.

In particular, case studies are developed for both countries focusing individually on hydrogen direct-use, hydrogen blended with natural gas as well as carbon capture and storage (CCS) and utilization (CCU; both together also abbreviated as CCUS). In these three technology-specific sub-chapters, we successively concentrate on country strategies, draw a picture of relevant research, development and demonstration (RD&D) projects and discuss challenges and perspectives. As regards the latter, we seek to provide an understanding of what hinders market penetration of these technologies and how these barriers can be overcome. We, therefore, sketch economic, technological, infrastructural, acceptance and other regulatory issues in different levels of detail. Following the two case studies, we compare the situation in both countries before providing country-wise recommendations for a way forward. While the industry perspective is the priority in both case studies, we try to open up the broader context, if relevant. For instance, in both countries, hydrogen is seen as a solution not only available to the industry sector, but stakeholders from other sectors also have an interest in making use of the technology pathway. Teams of country experts in the field of industry decarbonization carried out the case studies.

Through this study, the authors seek to contribute to the GJETC's objective to deliver strategic and systemic analysis in order to develop policy advice focused on problem solutions respecting the different framework conditions and energy policies in both countries.

2 Germany

2.1 Germany's basic materials industries

The basic materials industry is a relevant pillar of the German economy, with a total turnover of EUR 250 billion in 2017 and 550,000 direct employees. At the same time, industry produces 36.7% of Germany's greenhouse gas emissions (GHG) as of 2019, including both direct and indirect emissions (VCI, 2021). While indirect emissions are accounted to the energy sector in Germany, direct industrial emissions are at around 22% of total GHG emissions, of which 32% are process-related, for instance in steel, basic chemicals and cement production (Agora Energiewende & Wuppertal Institut, 2019). In addition, significant indirect emissions from electricity use suggest that increases in energy efficiency have a positive (climate) effect on the energy sector (BMU, 2018).[1 2]

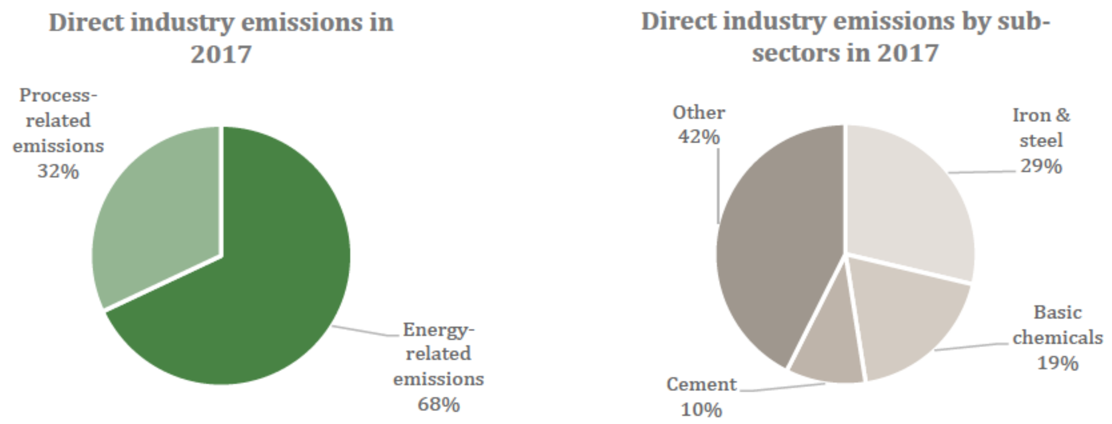

Figure 1: Key data for direct industrial emissions in Germany as of 2017 (based on Agora Energiewende & Wuppertal Institut, 2019).

Due to these process-related emissions, the transformation of these sectors towards climate neutrality is considered to be extraordinarily challenging (Agora Energiewende & Wuppertal Institut, 2019; Federal Government, 2016).

The lifespan of industrial facilities can be up to 70 years, so today's investments have implications for the future. By 2030, German-based production facilities will be facing substantial reinvestment decisions. For example, in steel production around 50% of blast furnaces will reach their end of life by 2030 (Agora Energiewende & Wuppertal Institut, 2019). However, investments in low-carbon facilities and/or their operation are often more expensive than conventional technologies, and as most basic materials are globally traded, companies fear competitive disadvantages, if transformative investments increase the sales price of their products.

In the following, policy strategies and research, development and demonstration activities as well as challenges and policy recommendations are highlighted for the three technology pathways, which are analyzed in this study, for German industry. These pathways are

- Hydrogen direct use
- Blending hydrogen with natural gas (HNG) and

[1] For instance, as of 2016, industry consumed 246.700 mn. kWh, of which the major share (214.700 mn. kWh) was provided through the grid counted as indirect emissions (BDEW, 2017).
[2] A sub-sectoral differentiation of data on direct and indirect emissions from the industry sector is not available, which is why the figure above focuses on direct emissions.

- carbon capture utilization and storage (CCUS).

2.2 Hydrogen direct use

2.2.1 Strategy

In Germany, hydrogen and, in particular, green hydrogen is seen as a central technology pathway to decarbonize hard-to-abate sectors including industry. Green hydrogen is produced from water and renewable electricity through electrolysis (Shibata et al., 2020). When industrial application cases are discussed for hydrogen, steel and chemistry production as well as refineries are mentioned frequently, including in Germany's National Hydrogen Strategy (NHS) published in 2020. For instance, in the steel sector, (green) hydrogen can substitute other CO_2-intensive production inputs, underlined by the Government's recently published Action Plan Steel. In the chemical industry and refineries, green hydrogen can substitute grey hydrogen, which is produced from natural gas (BMWi, 2020b; Federal Government, 2020a; Hebling et al., 2019).

In Germany, there are hardly any alternatives to green hydrogen in order to decarbonize industry, which is why a climate-friendly industry production and hydrogen development are closely connected. In contrast to that, if hydrogen is blended with natural gas, it would not be directed towards industrial purposes only but to other sectors, as well. However, the building sector, which relies on gas supply for heating is considered to have better alternatives, in general, such as direct electrification (e.g. through battery electric vehicles or heat pumps). Hence, blending hydrogen with natural gas is seen as wasting the green gas, and green hydrogen should be a priority for industry (BDI, 2019; BMWi, 2019a; Federal Network Agency, 2020).

Today, Germany's total hydrogen demand is at around 55 TWh, mostly from the chemicals and petrochemicals sector; the production of green hydrogen is negligible. In 2030, the Government expects a total (cross-sectorial) demand for hydrogen of 90 to 120 TWh (Federal Government, 2020a). For 2050, Germany's industrial demand for hydrogen may range between 94 and 145 TWh by 2050,[3] steel industry alone may require between 38 and 56 TWh by then (Hebling et al., 2019; MWIDE, 2020; Robinius, 2020).

In order to supply industry with hydrogen, the NHS outlines electrolysis development: the Government intends to develop 5 GW of domestic hydrogen generation capacity by 2030 and an additional 5 GW of hydrogen capacity is supposed to be added if possible by 2035 but no later than 2040. A comprehensive sector-wise planning for hydrogen applications does not exist so far with the exception of 2 GW of electrolysis capacity allocated to petrochemicals (Energieinformationsdienst, 2020; Federal Government, 2020b). Germany's

[3] These figures exclude the demand for hydrogen in the chemical industry.

hydrogen ambitions are also embedded the EU's plan to set up 40 GW of electrolyzers in the EU and another 40 GW in the EU's neighborhood countries by 2030 ("2x40 GW plan"). As an intermediate step, 6 GW of electrolysis capacity are to be installed by 2024 on EU territory (European Commission, 2020a).

In line with the domestic development of hydrogen production, the German Government plans to add renewable electricity generation underlining the focus on green hydrogen. However, domestic hydrogen production through electrolysis will only serve around 12 to 16% of the total (cross-sectoral) hydrogen demand expected by the NHS in 2030 (Federal Government, 2020a). Also due to the high demand for (green) hydrogen, some industry association wish for a more ambitious expansion of domestic renewable electricity capacities (VDMA, 2020). Hence, a key question will be, how the rest (> 80%) of the demand will be met, also pointing to the role of imports. The NHS acknowledges that blue and turquoise hydrogen will be traded globally and used domestically until green hydrogen is available at competitive prices (Federal Government, 2020a). Blue hydrogen is produced from natural gas using gas reforming in combination with carbon capture and storage technology in order to store CO_2 underground, while turquoise hydrogen is the result of methane pyrolysis producing solid carbon as a by-product.

While the Government does neither domestically nor internationally facilitate the production of blue hydrogen (Federal Government, 2020b), it has initiated several projects worldwide (from Chile to Morocco to Australia) facilitating green hydrogen production and investigating upon local and international value chains, modes of transportation and logistics (acatech, 2020; Fraunhofer IGB, 2020; Produktion, 2020).

The discussion on how to meet domestic demand for green hydrogen is also accompanied by the Government's relative reliance on natural gas. For the steel sector, the German Ministry for Economic Affairs and Energy acknowledges natural gas to be an essential element to bridge the transition towards a comprehensive hydrogen-based steel sector (BMWi, 2020b). In one of the most promising technologies for the steel sector, which is direct reduction of iron, the application of natural gas and hydrogen is possible with varying concentrations of natural gas and hydrogen (dena, 2019). Hence, if available at lower prices, industrial players will be inclined to make use of cheaper natural gas (instead of expensive green hydrogen). In the end, the application of hydrogen in the industry sector is to some extend also dependent on how natural gas is considered a "bridge technology"in Germany (and Europe) and at what costs it will be available.

A newly established steering committee will "decide on the further development and implementation of the Strategy" (Federal Government, 2020a). It is comprised of representatives from various ministries and supported by experts from academia, business and civil society. For instance, it publishes statements on policy adjustments such as in the case of discussions revolving around the renewable energy levy, which increases electricity prices and also affected green hydrogen production, until this was recently exempt from the renewable energy levy.

2.2.2 Snapshots on research, development & demonstration

As regards research, development and demonstration (RD&D) activities for the direct use of hydrogen, refineries as well as the chemical and steel industries are central. In the cement industry, another relevant emitter of CO_2 emissions, the application of hydrogen will only reduce energy-related emissions, but hydrogen will not contribute to reducing the sector's large-scale process-related emissions resulting from the deacidification of limestone. Such process-related emissions make up for two thirds of the CO_2 emissions associated with cement production (Verein Deutscher Zementwerke, 2020).

Today, several large-scale RD&D projects have been initiated (or completed), most of which have been focusing on various parts of the hydrogen value chain, as Table 1 displays.

Table 1: Snapshot on RD&D projects on hydrogen in industrial applications in Germany

Sector	Project and description	Value chain
Refinery	The companies BP and Audi Industriegas cooperated in a 30-day test-project to demonstrate the use of green hydrogen in refineries in 2018. Audi Industriegas produced and transported hydrogen to BP's refinery to desulfurize fuels (energate 2018).	• Production • Transport • Application
Refinery	In the project "REFHYNE", the company Shell started to realize a 10 MW electrolyzer, based on which the technology provider ITM Power seeks to draw lessons learned for a 100 MW facility (IN4climate.NRW, 2020a).	• Production • Application

Sector	Project and description	Value chain
Refinery	In the project “Westküste 100” (Engl.: West Coast 100) an electrolyzer of 30 MW will be installed and fed by offshore electricity with high(er) full load hours compared to other renewable energy technologies. Green hydrogen is, then, supposed to be used for aviation fuel production as well as for increasing hydrogen concentrations in the grid. Due to these two utilization options, green hydrogen demand is safeguarded. The project envisions a scaling up of the original electrolyzer by adding around 700 MW (Raffinerie Heide, 2020).	• Green production • Transport • Application • Blending
Chemicals	The project “GreenHydroChem” develops two electrolyzers (100 MW and 40MW), which are connected to the grid and to a regional wind farm. The existing hydrogen pipeline infrastructure will be expanded to connect the new production sites with large-scale consumers from the chemical industry (Fraunhofer IMWS, 2019).	• Green production • Transport • Application
Chemicals	In the “GET H_2 Nukleus”-project, a consortium of energy companies, pipeline operators and chemical companies installs an electrolyzer with a capacity of 100 MW, which is fed by an offshore wind farm and connected to refineries and chemical production facilities via a hydrogen pipeline of 130 km. The pipeline consist of former natural gas pipes, which have been retrofitted, and 50 km of new constructions (GET H2 Nukleaus, 2020).	• Green production • Transport • Application
Chemicals	BASF has tested methane pyrolysis, which allows to produce hydrogen from natural gas; biogas as feedstock is also possible. While the process of methane pyrolysis is electricity intensive, BASF is interested in using renewable electricity. An advantage is that carbon is derived in granular form and not as a gas. The solid material can be used as a fertilizer in agriculture (energate messenger, 2019).	• Turquoise production • Application

Sector	Project and description	Value chain
Steel	ThyssenKrupp Steel tests a new blast furnace process, in which hydrogen will become the reducing agent. In conventional processes, this function is performed by fossil carbon emitting CO_2. This, however, is avoided through applying hydrogen transported via truck to the location. If the test phase is successful, the project will be scaled up by 2022 and the plant will be fully connected to a hydrogen network nearby. The company estimates a theoretic emission reduction potential at around 20%. A milestone will be the transformation to direct reduction. The company declares to become climate-neutral be 2050 (Thyssenkrupp Steel, 2020).	• Transport • Application
Steel	ArcelorMittal plans the large-scale production and use of direct reduced iron (DRI) through a complete switch to hydrogen. For this, grey hydrogen from natural gas will be used initially. Given the demonstration projects location in Northern Germany, it is envisioned to use green hydrogen from offshore wind facilities once it becomes available at competitive costs. The company plans to start operation in 2023 (ArcelorMittal, 2019).	• Production • Application
Steel	The steel company Salzgitter AG, plans to develop a DRI plant operating with 35% green hydrogen produced on-site and 65% will be natural gas. Part of the "WindH_2" project is the development of seven wind power plants, three on-site and four in proximity to the site, which will feed into the electrolyzer. In a complementary project, the company demonstrates high temperature electrolysis, which makes use of waste heat from steel production (Salzgitter AG, 2019).	• Green production • Application

2.2.3 Challenges and perspectives

Economic issues

Most of the economic discussions regarding the hydrogen use in industries are about both CAPEX and OPEX, perhaps with a higher focus on the latter as these are more difficult to address through policy measures.

Relatively high OPEX for the application of (green) hydrogen in industry is also due to all the costs associated with hydrogen production. Literature suggests that costs for green hydrogen are around EUR 5-6 /kgH_2, while blue and grey hydrogen cost only EUR 2,1 /kg H_2 and 1.5 €/kg H_2, respectively.[4] For green hydrogen, investment requirements for electrolyzers as well as the procurement of electricity are central cost factors at the moment, which would have to be passed on to industry. Price drops of electrolyzers through switching from manual to (semi-)automated production as well as price increases of emission certificates (increasing costs of conventional production) may help to make green hydrogen cost more competitive (BDI, 2019; Bukold, 2020; World Energy Council, 2018). The EU's and Germany's hydrogen strategies to facilitate electrolyzer capacity abroad can also be seen as a lever to achieve economies of scale and gain learning curves for reducing costs for developing domestic capacities. Taxes, duties and levies have been applicable in Germany for using electricity, which is elementary for green hydrogen production, increase the costs of power purchase and, thus, the costs of green hydrogen production. Recently, green hydrogen production has been exempted from the renewable energy charge (Appunn, 2020).

High capital expenditures for low carbon breakthrough technologies such as DRI plants exacerbate respective investments. For instance, direct reduction through hydrogen is expected to increase costs of iron production by 36 to 61 % (Agora Energiewende & Wuppertal Institut, 2019). Hence, Germany's National Decarbonization Program in Industry can provide funding for upfront investments. Under this program, the Government plans to spend EUR 2 billion for investments of large-scale industrial facilities also making use of hydrogen to decarbonize manufacturing processes between 2021 and 2024 (BMU, 2021; Federal Government, 2019, 2020a). The program will fund research and demonstration projects and market introduction activities in the industry sector. The Government's Package for the Future that has been designed to mitigate the impacts of the COVID-19 pandemic makes available an additional EUR 7 billion for the hydrogen market ramp-up in Germany (as well as EUR 2 billion for international partnerships).

On the EU level, further funding opportunities exist. The Innovation Fund will assist in bridging the 'valley of death' for innovative industrial projects. The fund's preceding program, the NER 300, was restricted to energy sector projects (e.g. large-scale CCS), while the Innovation Fund also targets industrial activities specifically. The first round of applications shows that energy intensive industries in the EU submitted several hydrogen projects, showcasing their interest in this field. Moreover, Carbon Contracts for Difference (CCfD) will

[4] Costs reflect an EU average (Bukold 2020).

be implemented in Germany targeting the steel and chemical industries, at first (Federal Government, 2020a). CCfD are supposed to cover OPEX resulting from investments in low carbon breakthrough technologies.

Textbox: Brief introduction to carbon contracts for difference

While the concrete design is still discussed, CCfD are a contract between the state and an industry company that plans to realize a climate-friendly project. Both parties agree upon a strike price for avoiding CO_2 emissions, which is project-based (e.g. realization of a DRI-plant), set for around 20 years and above the current price for emission allowances. The cost difference between the strike price and the allowance price is paid from the Government to the company for every avoided ton of CO_2 (probably on an annual basis). In doing so, the contract ensures the company investing in low-carbon technologies against a low allowance price. As the allowance price is generally considered too low and too volatile, it does not create a sufficient incentive for investing in capital intensive projects. This is where CCfD become relevant (Agora Energiewende & Wuppertal Institut, 2019; BMWi, 2020b; Leipprand et al., 2020; Richstein, 2017; Sartor & Bataille, 2019).

Other instruments envisaged seek to create green lead markets for industry. For instance, the Action Plan Steel notes that a sustainable public procurement criterion for energy intensive products, a labelling scheme for climate friendly materials, and / or a quota for processing a certain share of climate friendly basic materials in a final product (e.g. a car) could help to pull capital-intensive climate-friendly technologies into the market. Last but not least, the EU discusses the design of a Carbon Border Adjustment mechanism, which seeks to create a level-playing field between climate-friendly products produced within the EU and materials produced conventionally abroad (Agora Energiewende & Wuppertal Institut, 2019; BMWi, 2020b; Leipprand et al., 2020).

There are several other instruments currently under discussion, but their individual design and their orchestration is still pending.

Technological issues

While a snapshot on RD&D projects has been given above (Table 1), technological challenges must be solved. For instance, in steel production, research must, among other things, focus on dynamic operation of DRI facilities with alternating hydrogen concentrations and potential implications on product quality.[5] Moreover, the new DRI production route might affect cross-industrial networks. For instance, today, cement industry makes use of slag from

[5] DRI facilities can, in principle, make use of hydrogen and natural gas in alternating ratios.

steel production, which avoids CO_2. However, if the steel industry applies direct reduction technology, the quantity and quality of slag changes and it is unknown whether this new slag quality is fit for purposes in the cement industry. Hence, the transition to a hydrogen-based production route might bring along negative side-effects in other sectors, which deserves attention. Moreover, small-scale demonstration plants must be scaled. Demonstration projects mentioned above (s. Table 1) seek to address this problem by starting demonstration projects small-scale with a gradual expansion (e.g. scale-up of electrolyzers) already intended in project proposals. Industries require a constant supply with hydrogen, drawing attention to the development of hydrogen storage technologies (Hebling et al., 2019; Verein Deutscher Zementwerke, 2020).

As for the international dimension of the NHS, some other technological advancements need to be taken into account. For imports, certain imports via ship remain challenging and need to be addressed. Apart from that, if hydrogen is produced in countries with water scarcity, the production of hydrogen might either require (additional) desalination facilities or the production of hydrogen from salt water (Wietschel et al., 2020).

Different instruments have been or are planned to be implemented aiming at facilitating RD&D for applying hydrogen in industry, even though a differentiation of those policy programs between the direct use of hydrogen and admixtures of hydrogen and natural gas would deserve a deeper analysis. These include:

- The National Innovation Program on Hydrogen and Fuel Cell Technology, which delivered EUR 120 million for industrial purposes between 2006 and 2016; more than 50% went into demonstration projects (BMVI & BMWi 2017); figures include public funding blended with private means. While transport and building technologies were the dominant funding areas in the original funding stream, its follow-up for the period between 2016 to 2026 has doubled the total amount of public funding to EUR 1.4 billion, so that more budget can be assumed to be also used for industry-relevant themes.
- The Government's Energy Research Program, which allocated EUR 100 million to "sector coupling and hydrogen technologies"; due to data constraints, an indication as regards the program's relevance for the industrial use of hydrogen cannot be made.
- The Energy and Climate Fund; for the period between 2020 to 2023, EUR 310 million will be facilitated to practice-oriented basic research on green hydrogen.
- Regulatory sandboxes also targeting hydrogen with EUR 600 million (Federal Government, 2020a).

Data covering all RD&D projects realized through Federal Government funding for hydrogen in industrial applications shows a substantial increase in public investment.

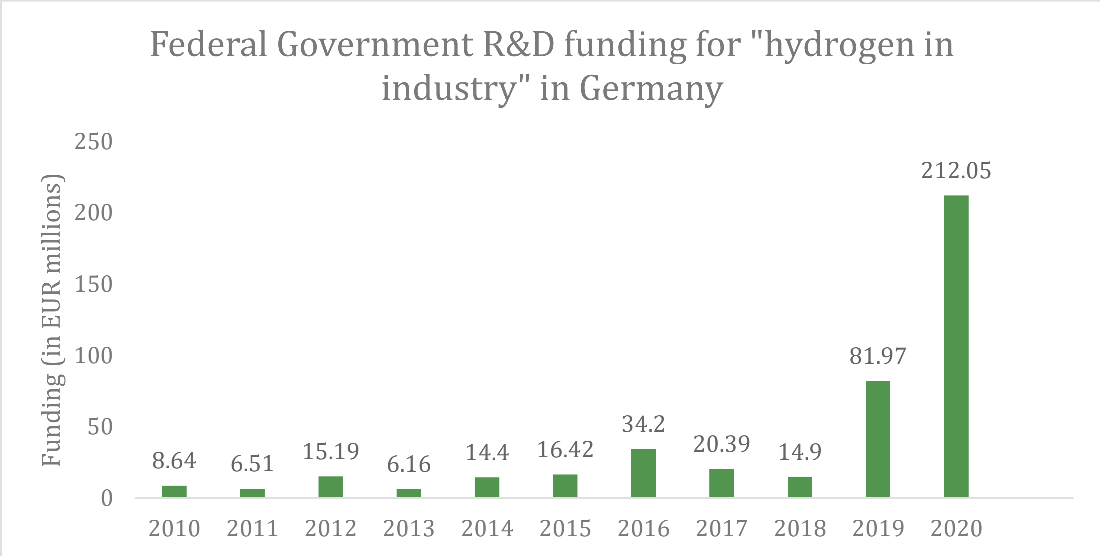

Figure 2. Federal Government funding for RD&D for "hydrogen in industry" in Germany, based on PTJ (2021).

Federal States have their own regional R&D programs, which take into account regional needs of respective companies. For instance, as of 2018, research in hydrogen technologies received another EUR 12 million from the Federal State Governments (Jessen, 2020).[6]

Infrastructural issues[7]

The German hydrogen infrastructure is limited at the moment. At present, there is very little electrolyzer capacity in Germany for green hydrogen production. The current industrial demand for hydrogen dwarfs green hydrogen supply, even though aforementioned research projects such as West Coast 100 and GreenHydroChem add some capacities. It will be crucial to realise RD&D projects seeking to scale-up electrolyzer capacities, if small-scale tests turn out to be promising business cases. While the NHS has set up objectives to install electrolyzer capacities, their locations are unknown so far.

In its stakeholder consultation for hydrogen network regulation, BNetzA (2020a) outlines three scenarios, which are not to be regarded as isolated from each other but are rather sequential (BNetzA 2020b). First, local hydrogen island networks develop around current and future demand centers in the chemical and steel industry (scenario I). Two of such pure but small-scale hydrogen networks exist already today in Germany (cf. BWMi 2019). These local island networks could then be connected with hydrogen transport pipelines delivering

[6] Funding provided by regional authorities is published with a delay of around two years.
[7] This chapter focuses on physical infrastructure due to its role in providing large quantities of hydrogen from production sites to demand centers. Trucks and ships also play a role in hydrogen delivery. However, literature suggests that pipelines will play the central role for importing hydrogen, especially if transport costs will not be reduced dramatically (Wuppertal Institut & DIW Econ, 2020)

hydrogen from other regions in Germany and beyond (scenario II). Scenario III, in which a hydrogen distribution grid becomes necessary for hydrogen filling stations targeting heavy transport, is less relevant for industry. These three scenarios are considered to be realistic by the majority of stakeholders taking part in the consultation process, but more concrete forecasting is necessary (Federal Network Agency, 2020).

Even though transport network operators of gas grids have published a draft proposal, in which they suggest to make more than 1,100 km of natural gas pipelines ready for pure hydrogen transport and construct 151 km new gas pipelines by 2030, of which 94 km will also be for pure hydrogen transport (FNB Gas, 2020; von Burchard, 2020), the planning processes for power and gas networks are not done in an integrated way. A more coordinated planning between power and gas infrastructure providers may realize optimization potentials for the overall energy system. For instance, hydrogen for industrial purposes could be produced on-site or regionally, for which electricity transmission lines need to be build connecting industrial centers with large-scale offshore wind farms. Another option is to produce hydrogen close to the wind parks and make use of hydrogen/retrofitted gas pipelines to safeguard supply to demand centers. A proposal exists to better coordinate energy infrastructure planning: a System Development Plan precedes both, the Network Development Plan Gas and the Network Development Plan Electricity, in order to elaborate cross-infrastructural questions (dena & BET, 2020). Others propose to establish an independent expert panel, which will assess infrastructural and cross-infrastructural demands and grid expansion (E3G, 2020). Policy-making will have to find a way to identify the ideal infrastructural design option (Hegnsholt et al., 2020) and should also coordinate the increasing policy initiatives by Federal States (MWIDE, 2020; Roland Berger et al., 2020).

For a European hydrogen network, cooperation between governments and pipeline operators will be key. But initiatives have been started already with a proposal to develop a European Hydrogen Network (Wang et al., 2020). While there are projects that deal with hydrogen imports and the construction of electrolyzer capacities abroad, including projects on green ammonia in Morocco or the HySupply project assessing the creation of a value chain for hydrogen imports from Australia to Germany, relevant information such as scenarios on hydrogen import needs and logistics are missing (acatech, 2020; Fraunhofer IGB, 2019; Hebling et al., 2019; Wietschel et al., 2020).

Further regulatory issues

Several of the above-mentioned topics would also deserve to be mentioned here, as regulators and policy makers can provide relevant support. However, this subchapter focuses on some new aspects as regards hydrogen production, pipeline transport and the creation of lead markets.

Advancing the certification of green hydrogen will safeguard that sustainability criteria for production are applied at a European level and internationally, if the criteria also address imports. It must also be avoided that green hydrogen producers are put in unfair competition with blue or grey hydrogen producers/importers. All types of hydrogen have the same application characteristics, but they differ in costs. Green hydrogen based on renewables is more expensive than, for instance, natural-gas-based (grey) hydrogen or (yellow) hydrogen produced from the current electricity mix still including coal power in Germany. In the end, a certification scheme will have to increase transparency of hydrogen supply to industry (and other users).

Future hydrogen sustainability criteria should not only safeguard that hydrogen is produced from renewable energy sources but go beyond a narrow definition. For instance, these renewable electricity capacities must either be *additionally* implemented or excess electricity must be used which would otherwise have been wasted (cf. Shibata et al., 2020 for a thorough discussion). Only if renewable electricity is not withdrawn from other utilization options, green hydrogen will be in line with climate objectives. In some countries with exceptional potentials for renewables and, thus, for green hydrogen, water scarcity plays an important and restrictive role. Hence, sustainability criteria for hydrogen production must be comprehensively thought through (Shibata et al., 2020). On the EU level, a project consortium seeks to set up a certification scheme for green and low carbon hydrogen called CertifHy. Internationally, the German Energy Agency has been assigned to development a certification system for green hydrogen and climate-neutral fuels in Australia, which will reflect the CertifHy initiative, showcasing Germany's commitment in this area (Peacock, 2021).

At the moment, *regulation for hydrogen networks* is pending, and there are different aspects to consider. For instance, regulation could guarantee access to the grid for industrial applications and prevent market abuse of hydrogen network operators. On the one hand, this would increase investment security of hydrogen producers and users. On the other hand, a regulatory approach might also result in costs due to operators being responsible for reporting substantial amounts of data to a regulating agency. The latter would also need to enhance its capacities to process and verify respective data. If the Government opts for a regulatory approach, the question is whether original transport network operators (TNOs) of gas networks will be in charge of building up the envisioned hydrogen network or whether this will be carried out by specialized hydrogen network operators (HNOs). TNOs will be able to easily retrofit network structures, which they own anyway. Specialized HNOs would have to engage with TNOs and negotiate the takeover of natural gas network structures for making them hydrogen-ready (EWI, 2020). Also based on the market consultation, the BNetzA will decide whether and how hydrogen networks will be regulated (Federal Network Agency, 2020).

According to the Renewable Energy Directive (2018/2001/EU), revised in 2018, Article 25 requires each Member State to "set an obligation on fuel suppliers to ensure that the share of renewable energy within the final consumption of energy in the transport sector is at least

14 % by 2030 (minimum share)" (European Commission, 2018). The revised Directive allows fuel producers / refineries to count emissions saved by making use of green hydrogen (e.g., in the desulphurization process). The German Government set the minimum share at 28%, which is effectively at 22% without double counting (dena, 2021). This allows for phasing in green hydrogen into petro-chemicals and, thus, the transport sector safeguarding demand for hydrogen producers.

2.3 Hydrogen natural gas blending

2.3.1 Strategy

The blending of natural gas with hydrogen (HNG) for industrial purposes is not prominently discussed in Germany's NHS. Blending hydrogen with natural gas is an opportunity to make use of Germany's existing natural gas network. However, depending on the hydrogen concentrations in a certain admixture, network upgrades (and, thus, investments) have to take place. As mentioned earlier, an HNG admixture is frequently rather seen as an option to decarbonize heating, in general. This, in turn, would waste the valuable hydrogen gas in sectors, which have better alternatives such as stronger energy efficiency and direct electrification, while industry hardly has any other options (BDI, 2019; DUH, 2020; EEB, 2021; Federal Network Agency, 2020). Some industrial actors are afraid that HNG admixtures create scarcity of green hydrogen, increasing prices. Proponents of blending green hydrogen with natural gas focus on the central role of the building (and heat) sector for a climate-neutral Germany. One of their key arguments is that although the energy efficiency of buildings needs to be increased, in fact, the building renovation rate has been lower than expected for many years. Hence, the gradual increase of green hydrogen concentrations would allow for decarbonizing Germany's building stock independent from renovation measures (BDEW, 2020). On the other hand, using green hydrogen for heating buildings would need ca. five times the amount of electricity compared to direct use of electricity with heat pumps (#source to be added).

The NHS recognizes the need to check for opportunities to increase the H_2compatibility of the natural gas network, which is, in principle, capable of transporting a gas blend with hydrogen amounting to 10 % by volume (Federal Government, 2020a). A share of 2 % by volume is what Germany's Federation of German Industries considers realistically possible for a nation-wide hydrogen blending. One of the reasons is to protect sensitive users including natural gas motors and turbines, most of which only tolerate very low shares of hydrogen concentrations in an HNG admixture today. Higher hydrogen concentrations are considered an option in areas without sensitive industrial users (BDI, 2019), stressing the role of blending rather for the heat and building sector.

In general, this part of the discussion factors in that hydrogen and natural gas are blended into a *single* HNG admixture provided through an upgraded pipeline network. If hydrogen concentrations increase, two main options for sensitive industrial users are at hand: a) to upgrade or exchange existing systems that allow higher hydrogen concentrations for operation or b) to, ultimately, separate hydrogen from natural gas, e.g. through membrane technology. Alternatively, c) HNG concentrations in transport or distribution pipelines connected to sensitive users remain within the limits of below 2 % by volume.

2.3.2 Snapshots on research, development & demonstration

With regard to infrastructure-related RD&D activities, different projects test increasing concentrations of hydrogen in isolated natural gas grids. Among others, concentrations of 20% and 30% by volume are applied. However, their focus is rather on heat and the building sector (Tenge & Brandes, 2019; Verband Kommunaler Unternehmen, 2020). An EU project with German stakeholder participation investigates upon the impact of high amounts of hydrogen on the gas infrastructure and its components (European Commission, 2020b).

On the application of HNG admixtures in industrial facilities, the HyGlass research project investigates the use of hydrogen in the glass industry and the implications on glass production. HyGlass is funded by the regional government of the state of North-Rhine Westphalia. The glass industry belongs to the group of sensitive users and given that hydrogen has different characteristics compared to natural gas, it becomes crucial to identify the impacts on material quality. In particular, different concentrations of hydrogen mixed with natural gas are taken into account in the analysis, from 10% to 100% by volume (BV Glas, 2020).

Other activities focus on the aforementioned separation of H_2 in a certain admixture with natural gas. Since German research projects found that membrane technologies have several advantages in contrast to chemical conversion processes, a demonstration plant will be set up in order to identify the best membrane technologies for separating different HNG blending ratios (DVGW, 2020; Lubenau & Kussin, 2020).

2.3.3 Challenges and perspectives

Economic and technological issues

The production of (green) hydrogen mixed with natural gas faces similar economic challenges as described in the chapter on the direct use of hydrogen (see 0). Apart from that, concerns are that hydrogen blending may create scarcity for the green gas, which would, then, increase its purchase price for industrial users relying on pure hydrogen.

Admixture poses technological challenges that will require investments. For instance, increasing hydrogen concentrations will affect hydrogen-sensitive industrial applications. The maximum share of hydrogen blended with natural gas is restricted to 2% by volume, if sensitive end-users are connected to the network including industries with gas-fired motors and turbines (Lubenau & Kussin, 2020). Next to projects for enhancing the pipeline infrastructure (European Commission, 2020b), the exact composition of the gas affects the combustion process and, thus, industrial applications: higher shares of hydrogen reduce the calorific value, which would require an adjustment of the gas flow in a furnace. Without an adjustment, the temperature would drop resulting in problems regarding the material quality of glass, for example. The aforementioned HyGlass project acknowledges this challenge and identifies the impacts of higher and varying hydrogen concentrations on glass quality (BV Glas, 2020). Moreover, another research project works on measurement and control technologies in order to identify fluctuating gas compositions in real time (IWR, 2020).

Apart from capital and time intensive exchange of certain equipment in relevant industrial applications in order to make use of HNG admixtures, other technologies separating hydrogen from natural gas are not considered to be market-ready yet such as membrane technologies. For instance, while membrane technology has a technology readiness level (TRL) of 9 for general industrial use, its readiness for separating H_2 from natural gas is considered much lower (TRL 5) with only some pilot projects being implemented (Lubenau & Kussin, 2020). Testing the latter is considered to be of high significance in future RD&D activities (BDI, 2019; DVGW, 2020; Fraunhofer ISI & DVGW, 2019; Lubenau & Kussin, 2020).

In a market consultation, quite a significant number of participants believed infrastructural planning should avoid an increase of hydrogen concentrations, in particular, in networks which hydrogen sensitive users are connected to. If hydrogen concentrations increase, others call for a funding program assisting industrial companies in financing the large costs associated with retrofitting or exchanging existing equipment or facilities (Federal Network Agency, 2020).

Infrastructural issues

At the moment, the role of hydrogen in Germany's grid infrastructure is largely unclear and includes discussions on the development of new structures for pure hydrogen as well as the rededication or retrofit of the existing networks. If hydrogen concentrations exceeding current restrictions are intended to increase nationwide, a strategy pointing to new framework conditions and necessary technological retrofits will be necessary. Due to European pipeline network, a dialogue at the EU level is key. Large-scale technology upgrades in infrastructure must be in line with long-term objectives of the Government; hence, unnecessary investments recurring every few years for increasing hydrogen concentrations in a step-by-step-approach in pipelines should be avoided (Fraunhofer ISI & DGVW 2019).

Further regulatory issues

The German Technical and Scientific Association for Gas and Water (DVGW) seeks to adjust its documents regulating hydrogen concentrations in natural gas networks in order to increase the H_2 shares in HNG admixtures by up to 20% by volume (Wirth, 2019). Apart from that, for transnational transport of natural gas blended with hydrogen, restrictions in receiving (and transit) countries must be factored in. The maximum shares in EU countries vary from 0.1 to 12% by volume. Hence, European harmonization is key.

2.4 Carbon capture utilization and storage

2.4.1 Strategy

The technology pathways of carbon capture and storage (CCS) and carbon capture and utilization (CCU) rely both on technologies relevant for capturing and transporting CO_2. As regards CCU, removed CO_2 is directed to other processes, where the CO_2 is absorbed for a certain period of time depending on the lifespan of the product. In the CCS-route, removed CO_2 is stored underground.

In order to understand the situation of CCUS in Germany, the more recent historic context is relevant. In particular, the role of onshore CCS was originally considered important for capturing CO_2 from power plants, but it has long been controversially debated raising massive public protest in respective regions. Most of Germany's onshore storage capacities are located in the North German basin, which is a relatively populated area. Skepticism *vis-à-vis* both the technology and the companies leading the project consortia (e.g. power companies such as Vattenfall and RWE) was huge.

Even though Germany's Federal Environment Agency (UBA) does not consider CCS a sustainable climate protection measure, it recognizes the need to continue RD&D, as other measures may not prove to be sufficient. Moreover, the discussion around CCS has shifted in a double sense. First, policy makers, industry and research investigate offshore storage capacities circumventing concerns by the larger population. Second, unavoidable process-related emissions from energy intensive industries enjoying hardly any alternatives (in contrast to conventional power stations) are in the spotlight now; and the role of CCS for such unavoidable process emissions has been acknowledged by stakeholders from different parties and societal groups as well as the Government (Federal Government, 2018; Fried & Kornelius, 2019; Nijhuis, 2020; Stratmann, 2020; WWF, 2019b). In particular, Germany's Ministry for the Economic Affairs and Energy (BMWi) works on CCS and participates in a European coordination instrument for facilitating CCS (and CCUS) projects. The Industry Strategy 2030 mentions CCUS briefly stressing the role of RD&D (BMWi, 2019b).

In a way, the discussion on capturing CO_2 has also shifted towards its utilization (CCU), which has not raised massive public resistance yet. In contrast to the technology pathway of hydrogen, however, CCUS does not enjoy any technology-focused strategic outline by the government describing, for instance, how much CO_2 will be stored and / or utilized and by when. The NHS acknowledges CCU's relevance and hydrogen-based business models are mentioned to integrate CO_2 as a further resource input. For instance, in the chemicals sector, CO_2 and hydrogen can be combined to produce chemicals. Given that industrial representatives belong to the newly established hydrogen steering committee, it should contribute to bringing the technology pathways of hydrogen and CCU together. The Ministry for Education and Research facilitates CCU (Federal Government, 2018; Mennicken et al., 2016).

In the absence of a Government strategy, the German cement industry published a CO_2 roadmap to decarbonize the sector by 2050. The document differentiates between an "ambitious scenario" and a "climate-neutral scenario". In the former, important innovations are realized (e.g. application of CEM II/C-cements), but CCUS is *not* considered. In this ambitious scenario, 19% and 36% of CO_2 emissions are avoided by 2030 and 2050, respectively, compared to 2019. In the climate neutral scenario, 27% of CO_2 emissions are avoided by 2030, while in 2050 the sector is climate neutral. The climate-neutral scenario includes highly innovative developments (e.g. CEM IV-cements), of which CCUS is a key element. In this scenario, CCUS is relevant for 50% of CO_2 emissions avoided suggesting that hopes of the cement industry rely to a large extend on this technology pathway for a climate-friendly transition of their sector (Verein Deutscher Zementwerke, 2020).[8]

2.4.2 Snapshots on research, development & demonstration

Current research mostly focuses on carbon capture and utilization. Projects listed in the following Table show that research is mostly interested in investigating carbon capture and carbon utilization.

[8] A differentiation between the roles of CCS and CCU as regards their impact on CO2 avoidance has not been made. Since the study acknowledges that the market for utilizing CO2 is small in size, it can be suggested that the focus of the paper is on CCS (cf. Verein Deutscher Zementwerke, 2020)

Sector	Project and description	Value chain
Cement	An EU project called "Low Emissions Intensity Lime & Cement" (LEILAC), in which the German company Heidelberg Cement participates, investigates upon CO_2 capture technologies for cement production in Belgium. While it is stated that both utilization and storage might follow the initial research activities, the intended publication of a CCS roadmap suggests that CCS is considered the more likely option (Leilac, n.d.). This LEILAC approach is highly electricity-intensive: if 50% of Germany's cement production switched to this process, an additional 18-25 TWh of electricity would be necessary (Agora Energiewende & Wuppertal Institut, 2019).	• Carbon capture (Leilac approach)
Cement, petro-chemicals	In the project "catch4climate", the cement company Schwenk seeks to test oxyfuel technology for capturing CO_2 on a semi-industrial scale. The project consortium applied for funding, permission is pending. Schwenk seeks to forward CO_2 to the production of aviation fuels (Agora Energiewende & Wuppertal Institut, 2019; Schwenk, 2020).	• Carbon capture (oxyfuel) • Utilization
Steel, chemicals	The consortium of the project "Carbon2Chem" consists, amongst others, of the Companies ThyssenKrupp, BASF, Covestro and Linde. It can be considered a cross-industrial consortium between different sectors of the basic materials industry. The project aims at making use of CO_2 and H_2 from metallurgical gases produced in a steel plant for chemical purposes, e.g. methanol and ammonia production. Renewables provide the electricity for this conversion process. The second phase has been granted EUR 75 million. The process will be validated and upscaled by 2025, so that the chemical industry can make use of sequestrated CO_2 in an industrial scale (BMBF, 2020a).	• Carbon capture • Utilisation

Sector	Project and description	Value chain
Energy, chemicals	The energy company RWE operates a post-combustion carbon capture facility in one of its conventional power plants supplying CO_2 for the production of methanol, of which the EU is a net importer. In the "Mef CO_2"-project [9], excess electricity from renewables has been used for green hydrogen production. Researchers working in the project suggest that CO_2 capture is commercially viable and sustainable if used for higher-value chemicals. The technology investigated is considered to be transferable to other industries (European Commission, 2020c).	• (Green hydrogen production) • Carbon capture • Utilization
Chemicals	In the project series called "DreamProduction", the chemical company Covestro and others succeeded in producing polyether-carbonate-polyols with CO_2. These polyols are an input for foam mattresses, for example, whose new material quality is considered outstanding. In the wake of the pilot stage, a commercial plant was realized. The CO_2 footprint was reduced substantially as the CO_2 is provided by a chemical plant close to the production site. Hence, this aligns companies of a single sector within the basic materials industry. In the Rheticus project, the companies Siemens and Evonik develop a technology to produce high-value chemicals (butanol, hexanol) from CO_2, power and water. These chemicals are inputs for special plastics, fuels and cosmetics. Together with the company Beiersdorf, Evonik plans to set a business model (BMBF, 2020b; IN4climate.NRW, 2020b).	• Utilization

[9] MefCO2 stands for "synthesis of methanol from captured carbon dioxide using surplus electricity".

Apart from the petrochemical industry, research also focuses on CO_2 as an ingredient for cement production. However, the process is relatively electricity intensive and lacks a business case (Ostovari et al., 2020; WWF, 2019a).

2.4.3 Challenges and perspectives

Economic issues

In the field of CCUS, economic issues revolve around carbon capture technologies and carbon utilization. CO_2-capture and utilization are both electricity-intensive processes resulting in a higher electricity consumption. In order for CCUS to have a positive climate effect, electricity needs to come from renewable sources – at competitive prices (adelphi & IASS, 2016; Verein Deutscher Zementwerke, 2020). For CO_2 storage offshore, costs are higher compared to an onshore option (Federal Government, 2018)

Products resulting from removed CO_2 vary in competitiveness. While the production of polyols is considered to be a business case, the production of synthetic methane and methanol suffers from relatively high prices. In this respect, the availability of green hydrogen is considered a bottleneck for the CCU route also requiring renewable electricity for electrolysis (acatech, 2019). Moreover, the capacity of the chemical industry and refineries to make use of CO_2 from other sectors is only about to take off. Hence, the demand for CO_2 is low, affecting the price of CO_2 as a raw material, and provides few opportunities to develop cross-industrial business models (Verein Deutscher Zementwerke, 2020). The following figure shows the market-readiness of certain CCU products from the chemical industry.

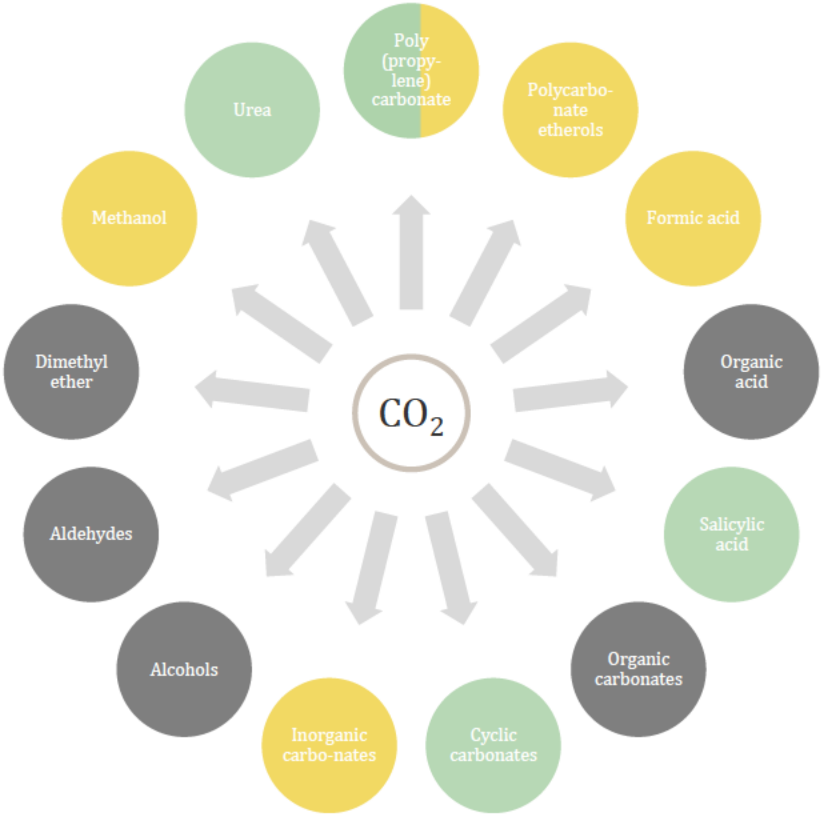

Figure 3: CCU products and their market-readiness based on (acatech, 2019); green: commercial scale, yellow: demonstration scale, dark grey: laboratory scale.

Financial assistance for capture and utilisation technologies and / or a higher price tag on CO_2 for conventional production may increase CCUS' market deployment. With regard to CCU, synthetic methane would require a CO_2 price of EUR 90 per tonne of CO_2 to become a business case, which is more than three times the current allowance price. In its Climate Action Programme 2030, the Government introduces the program for CO_2-Avoidance and Utilization in Basic Materials Industries, which, among other things, seeks to facilitate a carbon circular economy, adjust and scale-up methods to capture CO_2 in industrial uses and develop regional, transregional and European CO_2 networks. Moreover, the National Decarbonisation Programme provides grants for the uptake of technologies for utilising CCU (Federal Government, 2019). Upfront investment can also be supported via the EU's Innovation Fund, while the instrument of Carbon Contracts for Difference supporting OPEX will be implemented soon; however, so far, discussions focus on implementing CCfD as a means to facilitate hydrogen in industry and not on CCUS, even though literature suggests that, for instance, CCfD can be a lever for oxyfuel technologies (see chapter 2.4.1 for an overview of CCfD).

Other recommendations for supporting the CCUS uptake revolve around tax allowances for CO_2 utilization (Bazzanella & Krämer, 2017), the design of lead markets, in which consumers are informed and enabled to purchase CO_2-efficient or -free products such as cement or concrete, and life-cycle analysis for the CO_2 performance of products (Verein Deutscher Zementwerke, 2020).

Technological issues

The following figure provides an overview of RD&D funding priorities of the Federal Government in the field of CO_2 technologies. It shows that investment increased from 2016 onwards focusing on basic research and CO_2 utilisation and conversion. As the newly established funding schemes mentioned above also facilitate RD&D, it can be assumed that figures will very likely increase.

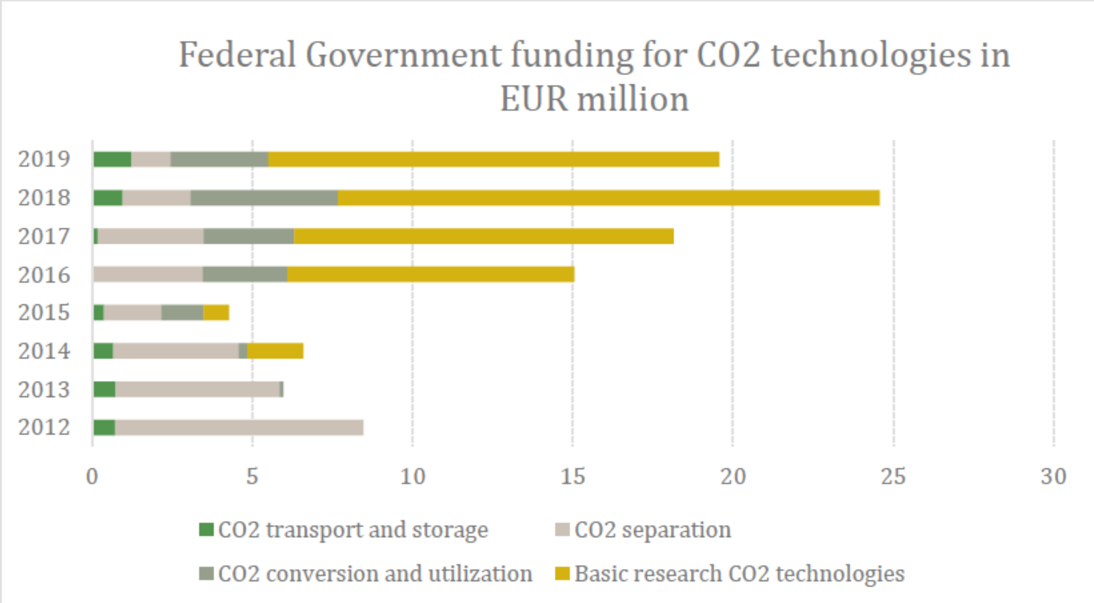

Figure 4: Federal Government funding for CO_2 technologies in EUR million based on (BMWi, 2020a)

Some technological challenges remain in the field of CO_2 capture in industrial plants, where they need further demonstration (acatech, 2019; Markewitz et al., 2017). Due to the high energy demand of CO_2 removal technologies with industrial sites, it is key to facilitate energy efficiency, which will also reduce the need to expand renewable power plants (WWF, 2018). CO_2 transport is a mature technology also reflected by the lack of R&D budget attached to this element of CCUS. For onshore storage, if this unlikely pathway were taken up again, further feasibility studies for saline aquifers would have to be carried out (Markewitz et al., 2017). A key point of critique has been the unknown implications of underground storage on groundwater and soils and risks of CO_2-leaks; challenges would need to be solved for progressing in the field of onshore storage (adelphi & IASS, 2016).

For offshore CO_2 storage in the North Sea region, close cooperation with European partners is envisioned in Germany's Industrial Strategy 2030 (BMWi, 2019b). As offshore storage is more expensive, research may focus on identifying low-cost solutions.

For the utilization of CO_2, literature suggests a RD&D focus on the lime and cement industry and on products and processes resulting in substantial CO_2 savings, particularly on those products with a strong capacity to store CO_2 over a long period of time such as buildings (adelphi & IASS, 2016) as well as on reducing energy demand for chemical conversion processes (Bazzanella & Krämer, 2017).

Textbox: Carbonation

The process of carbonation, also called mineralization, makes use of CO_2 as a feedstock. In this process, CO_2 is reacted with other substances (e.g. ash, sand) to certain carbonates / minerals. These minerals can, in turn, be used for developing cement- or concrete-like building materials. Carbonated cement can be mixed with ordinary Portland cement to realize a blended type of cement. Carbonation can also recycle former building materials, which would contribute to establishing a circular economy in the construction sector. However, research needs to advance this process and regulations for building materials would have to be updated (Agora Energiewende & Wuppertal Institut, 2019; Ostovari et al., 2020; WWF, 2018).

As areas of research, the following are acknowledged by the Government (BMWi, 2019b):

- capture technologies for industrial plants,
- regional and European CCS/CCU infrastructure of other new CO_2 use options, and
- reducing CO_2 abatement costs.

Germany's research ministry BMBF funds research on CCU and PtX. For instance, several of the above-mentioned research projects have received funding by the ministry, including Carbon2Chem and Rheticus.

Another issue discussed is whether CCU technologies truly reduce environmental impact. Life-cycle assessments can help to figure out the environmental impact of CCU. Today, CCU-focused LCA-studies cannot be compared and are very complex, not least because several CCU-technologies are only in the development stage. Projects have been initiated to figure out what an LCA for CCU can look like (DG ENER, 2020; Müller et al., 2020).

Infrastructural issues

Infrastructural issues revolve around production sites, transport, demand centers for CO_2 use and capacities to store CO_2.

While industrial networks / clusters exist, where one industrial player can provide CO_2 to another one, as demonstrated by the Carbon2Chem project, these clusters are limited in quantity. This, in turn, raises questions regarding the development of a CO_2 infrastructure. If large quantities of CO_2 need to be transported from suppliers to storage or demand centres, a pipeline infrastructure might be a central option. However, fears exist that carbon capture technologies and particularly a pipeline-based infrastructure may result in lock-in effects, which keeps traditional business models alive while, hindering the realization of more climate-friendly solutions. In other words, once infrastructures are set up, their economic operation requires sufficient quantities of CO_2 to be transported. Avoiding such lock-ins must be part of a Government strategy, which must safeguard that the utilization of CO_2 does not go hand in hand with slower GHG reduction (adelphi & IASS, 2016; Ausfelder & Dura, 2019).

The lack of overall planning of a CO_2 infrastructure results in reluctance to invest in individual but interdependent links in CCUS value chains. For instance, companies wishing to capture CO_2 do not know whether infrastructural preconditions will be available once the investment is realized, while investors in transport and storage facilities remain in the dark whether and by when CO_2 delivery may begin. An opportunity can be to develop a so-called market facilitator, whose task is to “plan infrastructure projects, provide funding and assume liability and risks, so creating the necessary certainty and security for each link in the process chain” (acatech, 2019).

In a very rough estimation, CO_2 captured by the German cement and concrete industry would require 500.000 truck rides per year, even though CO_2 transport will need a more differentiated approach also including ships and, above all, a pipeline infrastructure as its backbone. Concepts for (trans-)regional CO_2-infrastructures would have to be developed (Verein Deutscher Zementwerke, 2020), which is also addressed through the program for CO_2 Avoidance and Utilization in Basic Materials Industries and reaffirmed by Germany’s Industry Strategy 2030, both of which are, however, relatively unconcrete (BMWi, 2019b; Federal Government, 2019).

Facilities to capture, utilize and store CO_2 require electricity based on renewables in order to have a climate effect. To apply CCUS, industry players require renewable energy to be available all over Germany. However, it has been estimated that very high amounts of electricity from renewable energy sources would be needed to achieve this, so that using the green electricity for substituting fossil fuels in other applications would have priority. This, in turn, shows that it is essential to have a CCUS strategy to be coordinated with renewable expansion planning (acatech, 2019). For decarbonizing cement and concrete, the respective association requests a renewable energy expansion to happen country-wide.

As regards CCS, potential onshore storage capacities in Germany exist, but given strong public resistance it is unlikely that these potentials will be realized. As long as these persist, undersea storage might be the better option despite higher costs (acatech, 2019). Huge storage capacities in Europe exist beneath the North Sea and the Norwegian Sea.[10] If CO_2-storage is restricted to industrial emissions, these capacities will be sufficient for many decades (acatech, 2019; Federal Government, 2018).

[10] For a discussion on blue hydrogen from Norway, see (Shibata et al., 2020).

Further regulatory issues

The legal regime for CO_2 pipelines is considered to be “rather rudimentary” reflecting the “lack of maturity and corresponding experience as well as the absence of mind of the legislator in regard to CO_2 transport” (Benrath et al., 2019). However, whether this weak CO_2 transport regime would prevent a valid business case from being realized has not been analyzed. While Germany’s Carbon Dioxide Act (KSpG) introduced in 2012 allows the capturing and transportation of CO_2 in unlimited quantities, the law *de facto* prohibits CO_2-storage onshore (acatech, 2019; Federal Government, 2018). At present, even discussions revolving around the production of blue hydrogen do not appear to open the door for an adjustment of this policy (Federal Government, 2020b). For transporting and particularly for storing large quantities of CO_2, a revision of the legal regime appears to be necessary. Another important legal challenge for the implementation of a European CCS infrastructure has been overcome in late 2019; the London Protocol, which forbade the transport of CO_2 from one country to another for offshore storage, does no longer stand in the way of cross-country CO_2 transport for offshore storage (IEAGHG, 2019).

Acceptance issues

Four projects initiated at the end of the 2000s originally aimed at storing CO_2 in geological formations onshore. Three of the four projects faced public resistance of people and societal groups in the respective region. These three projects sought to store CO_2 on a large scale and were led by industry players viewed critically by the people. In these contexts, communication and information campaigns did not result in higher acceptance. The only project that was largely accepted by the public was of scientific nature and limited in scope; both factors are assumed to have had a positive effect (Federal Government, 2018). It needs also to be acknowledged that CO_2-storage from power plants has alternatives such as increasing energy efficiency and the use of renewable energy. People living close to potential storage facilities located in the East and North of Germany felt to bear all the risks associated with CO_2 emissions mostly produced in Southern and Western Germany.

Moreover, the case in Germany has shown so far, that onshore storage is hardly accepted (Federal Government, 2018). Today, almost two thirds of Germans surveyed are either very concerned or fairly concerned as shown in the following figure.

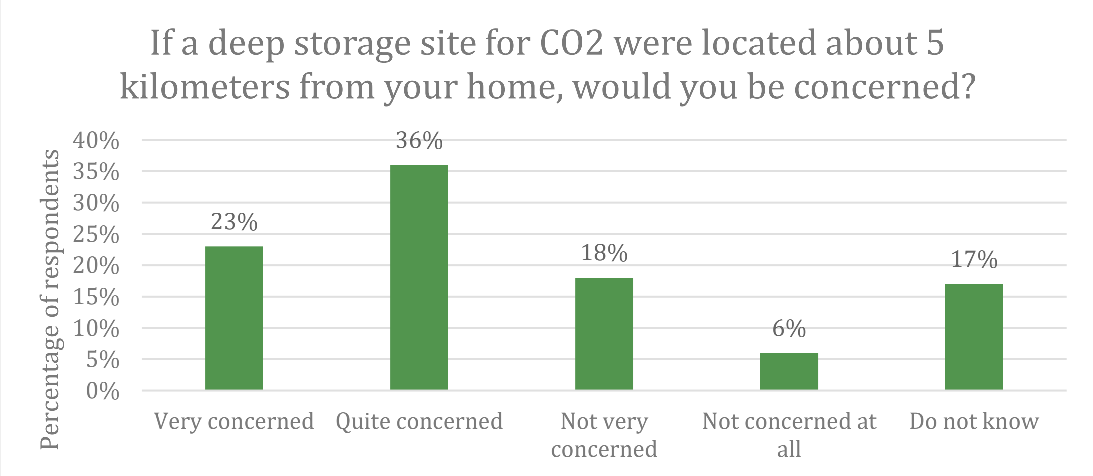

Figure 5: Public acceptance of CCS in Germany (based on Statista, 2021)

Literature indicates that public acceptance in Germany might be higher if industrial emissions are stored underground in comparison to emissions from power stations (Dütschke et al., 2016; Federal Government, 2018). However, in the end, it remains open whether old reservations can be overcome by a new approach to the overall debate on CCS, even though some environmental NGOs today advocate CCS (WWF, 2019b). Still, it is seen as key to embrace societal actors in any further steps regarding CCS. Given the low acceptance of onshore storage, offshore storage is seen as a better alternative with higher monetary but lower political / acceptance costs.

CCU has, so far, not raised major public reservations (Federal Government, 2018), even though a flagship research project on Power-to-X financed by the Ministry on Education and Research distills two positions on the use of CO_2. While some argue for either using sustainably cultivated biomass and direct air capture as the only ways for the technology to operate in a climate neutral way in the long run, others embrace the role of industrial sources (Ausfelder & Dura, 2019). In how far these positions will feed into public discourse is unclear yet.

For the debate on CCU, it also needs to be acknowledged that CO_2 can be stored for very different time scales—from weeks to multiple decades, depending on the final product (e.g., synthetic fuels vs. materials in buildings). In particular, the role of CCU for synthetic fuels is debated as the fuel is combusted relatively quickly emitting the CO_2, which has captured originally. Apart from that, the expansion of renewables necessary to generate synthetic fuels is problematic (WWF, 2018).

3 Japan

3.1 Japan's basic materials industries

Moving towards carbon neutrality has been accelerating globally. In October 2020, Japan jumped on the 'net-zero bandwagon' as Prime Minister Suga announced that Japan would achieve carbon neutrality by 2050. Hydrogen and carbon capture utilization and storage (CCUS) are critical technologies to reduce CO_2 emitted from the industry sector, for which it is hard to abate CO_2 emissions otherwise.

Similar to Germany, the basic material industries lead the manufacturing sector in Japan[11]. In 2018, the number of persons engaged was about 1.4 million and the value of manufactured goods shipments was JPY 62 trillion (EUR 480 billion) in these industries, equivalent to a share of 18% and 22% of the manufacturing sector, respectively (Ministry of Economy, Trade and Industry (METI), 2020b).

According to the preliminary data published by the Ministry of the Environment (MOE), Japan's CO_2 emissions in fiscal year (FY) 2019 were 1,106 million tons, of which 93% were energy-related emissions. The industry sector accounted for the largest part of 39%, which consisted of 35% of energy-related emissions and 4% of industry process-related emissions (Figure 6) (MOE, 2020). CO_2 emissions of the industry sector had gradually decreased due to improved CO_2 emission intensity per electricity generated and energy consumption decreases as a result of energy efficiency enhancement. Still, further efforts to mitigate CO_2 emissions are expected for the industry sector since they will affect whether or not Japan's commitment to carbon neutrality would be achieved by 2050. Among others, the iron and steel industry and the chemical and petrochemical industry made up more than half of the CO_2 emissions of the sector. Then, hydrogen and CCUS have come into the picture to enable these industries to become carbon-neutral.

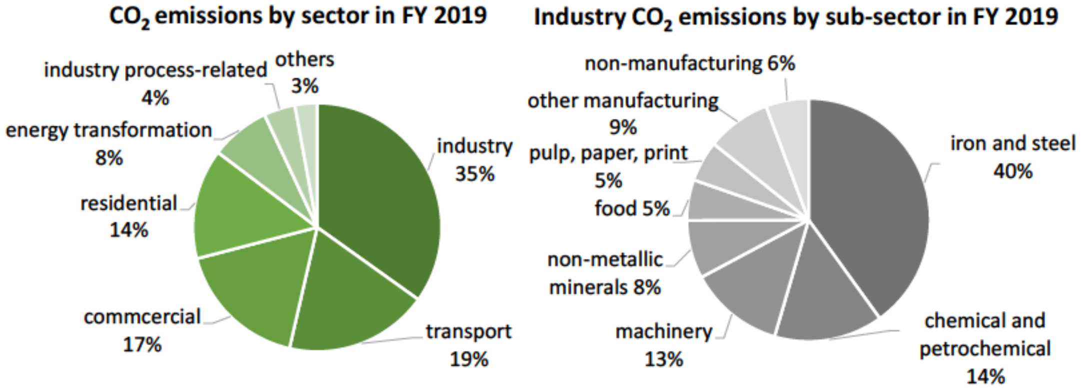

Figure 6: Key CO_2 emission data for industry in Japan (based on MOE, 2020).

[11] The basic material industries include chemical, pulp/paper, and non-metallic minerals.

3.2 Hydrogen direct use

3.2.1 Strategy

Japan has developed its first Hydrogen and Fuel Cells Strategic Roadmap (mentioned as the "Hydrogen Roadmap" hereafter) in 2014, which has been revised twice in 2016 and 2019. Japan has also published the Hydrogen Basic Strategy (mentioned as the "Hydrogen Strategy" hereafter) at the end of 2017. In both the Hydrogen Roadmap and the Hydrogen Strategy, hydrogen's application in the industry sector was not mentioned much. The main focuses of hydrogen/fuel cell's application in Japan have been hydrogen power generation, fuel cell vehicles, and Enefarms (small scale fuel cell co-generation unit for households).

However, after the announcement of the carbon neutrality target in 2020, Japan's hydrogen strategy is likely to be revised significantly. One of the revisions would be hydrogen's application in the industry sector. In the Green Growth Strategy towards Carbon Neutrality by 2050 (mentioned as the "Green Growth Strategy" hereafter) published in December 2020, the Japanese government envisioned that by 2050 hydrogen's demand from industry sector could be 7 million tons/year (233 TWh/year[12]), combining with hydrogen consumption for power generation (5-10 million tons/year (167-334 TWh/year)) and for transport (6 million tons/year (200 TWh/year), especially trucks and buses), low-carbon hydrogen (including green and blue hydrogen) supply to Japan is expected to be around 18-23 million tons/year (600-767 TWh/year) (METI, 2020f).

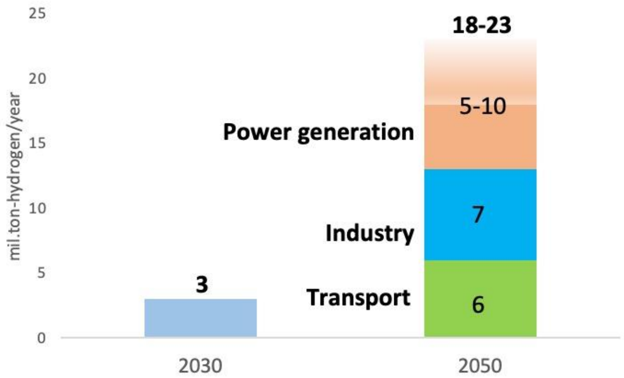

Figure 7: Hydrogen demand in Japan envisioned by the Green Growth Strategy (based on METI, 2020f).

3.2.2 Snapshots on research, development & demonstration

The Fukushima Hydrogen Energy Research Field (FH2R), located in Namie town Fukushima Prefecture, is the largest green hydrogen project operating in Japan. The system supplies electricity from a 20MW solar PV plant to a 10MW-class water electrolysis unit for green

12 Energy value of hydrogen (LHV): 120MJ/kg

hydrogen production. The system has the capacity to produce, store, and supply up to 1,200Nm^3 hydrogen per hour. FH2R aims to maximize the utilization of renewable power despite its intermittency and to establish low-cost green hydrogen production without battery system. Green hydrogen produced by the system will be used to power stationary fuel cells as well as to supply to hydrogen refuelling stations, and other applications including industrial sector. The project is supported by the New Energy and Industrial Technology Development Organization (NEDO) and is carried out by Toshiba ESS, Tohoku Electric Power Co., Inc., and Iwatani Corporation.

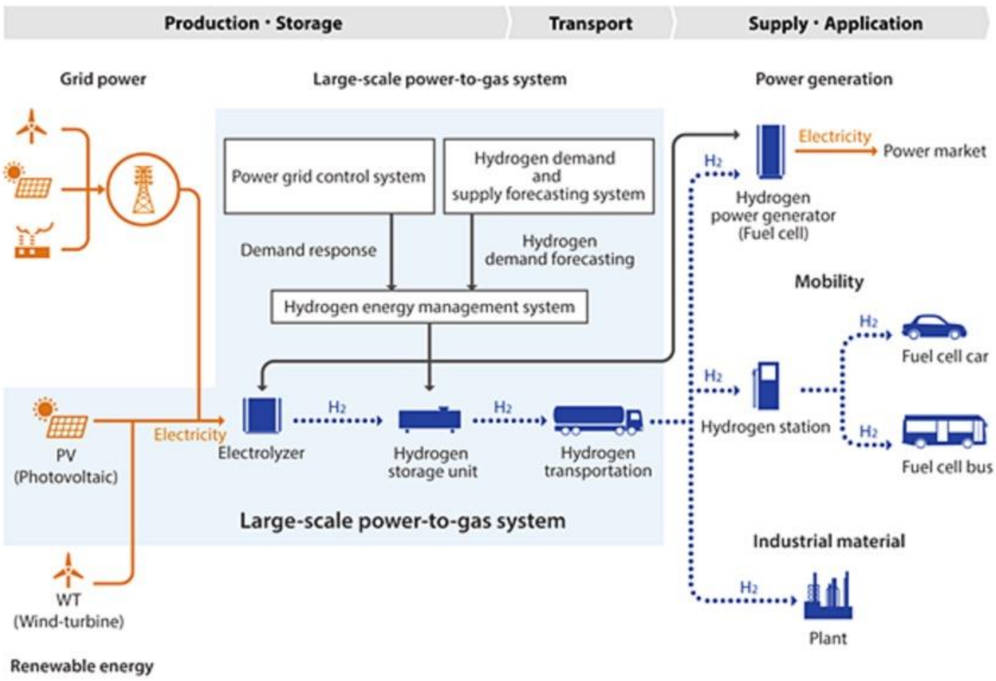

Figure 8: Framework of FH2R (Source: NEDO, 2020a).

One of the noteworthy projects on hydrogen's direct use in the industry sector is the COURSE50 (CO_2 Ultimate Reduction in Steelmaking Process by Innovative Technology for Cool Earth 50) initiative. The initiative started from 2008 and activities under the initiative are managed by the Japan Iron and Steel Federation. NEDO provides funds for the initiative. Hydrogen direct reduction and CO_2 capture are two pillars of COURSE50. The initiative aims to reduce CO_2 emission in steelmaking by 30% till 2030 and fully industrialize and adopt the new technologies by 2050. Japan's major steel makers are participating in the initiative.

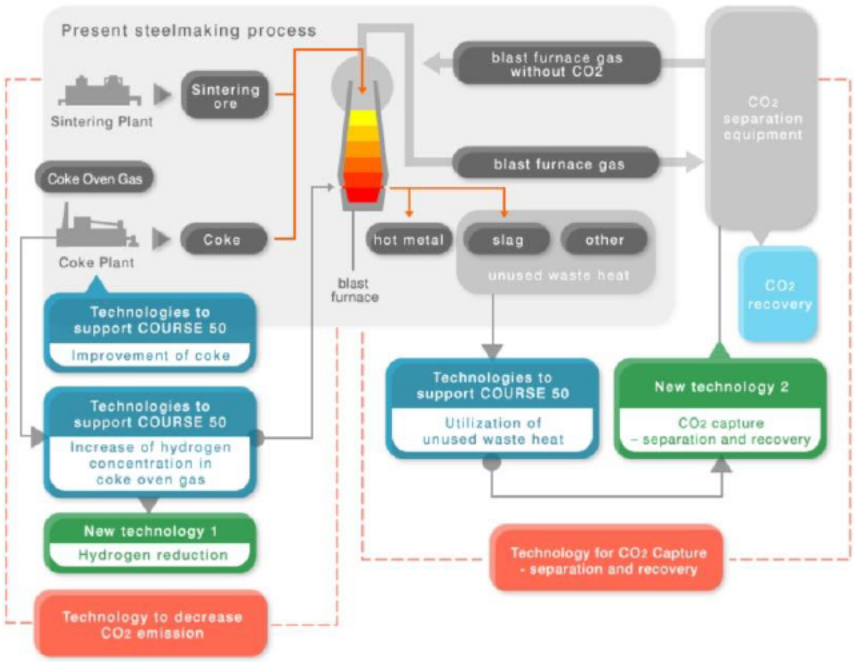

Figure 9: The COURSE50 Initiative (Source: Japan Iron and Steel Federation, n.d.).

The two cases mentioned above are all supported by NEDO, an agency overseen by the METI. Meanwhile, the MOE also implements a hydrogen demonstration program in cooperation with local governments. Main purpose of the MOE's program is to support domestic hydrogen production and hydrogen's application in local communities.

Table 2: Demonstration projects supported by the MOE

	Location	Partners	Source of hydrogen	Application	Scale	Period
1	Yokohama, and Kawasaki city	TOYOTA, etc.	Hydrogen produced by wind power	FC forklift	-Wind: 1980kW -Electrolyzer: 10Nm3/h -Trucks for hydrogen refueling: 270 Nm^3 * 2 units	FY2015~ FY2018
2	Hokkaido	Air Water, Kajima Corporatio	Hydrogen production from biogas	Hydrogen Refuelling Station (FCV, forklift), and	-Hydrogen storage at HRS: 739 m^3	FY2015~

		n, Nippon Steel P&E, Air Products		stationary hydrogen fuel cell		
3	Yamaguchi prefecture	TOKUYAMA, TOSOH, etc.	Byproduct hydrogen (NaOH)	HRS (FCV, forklift), Hydrogen FC , hydrogen pipeline	- Hydrogen FC: 100kW	FY2015~ FY2019
4	Kawasaki city at Kanagawa Prefecture	SHOWA DENKO, TOSHIBA, Daiwa House, MIZUHO	Hydrogen production from wasted plastic	Hydrogen supplied to hydrogen FC by pipeline Hydrogen supplied to HRS by trailer	-Hydrogen FC: supply 30% energy consumption at a hotel; -HRS: can supply hydrogen to 5~6 FCV per day	FY2015~
5	Hokkaido	TOSHIBA, Iwatani	Hydrogen production by micro hydro power	Hydrogen FC FCV	-Hydro power:200kW -Electrolyzer: 35 Nm3/h -Stationary FC: 100kW/7kW/3.5kW	
6	Miyagi	Hitachi, Marubeni	Hydrogen produced from power from rooftop Solar PV on a logistic center	Hydrogen storage and delivery: metal hydride Hydrogen FC installed at households, one super market, and one hospital		August 2017~
7	Akita	NTT data, Mitsubishi Kakoki Kaisha, OHMORI-KENSETSU, Dainichi Machine	Hydrogen produced from wind power and battery storage	Hydrogen blended gas (hydrogen blended with domestic produced gas) that meets the city gas standard Testing the compatibility of the	-Wind: 39.1MW -Battery: 24.192MWh	FY 2018~

		and Engineering, Aisin,		blended gas with gas appliances including gas stove, gas co-generation engine, small size gas boiler, and Enefarm		
8	Hokkaido	Taisei Corporation, Kyushu University, The Japan Steel Works, Ltd., Tomoe Shokai Co., Ltd.	Hydrogen produced from wind power	Low pressure hydrogen transport (metal hydride) Hydrogen supplied to stationary hydrogen FC	-Wind: 1,000kW -Hydrogen production: 1Nm3/h -Metal hydride tank: vehicle mounted 45Nm^3, fixed 45 Nm^3 -Hydrogen FC: 700W -Hydrogen transport vehicle: 2t (container attachable/removable)	FY 2018~
9	Fukuoka	Kitakyushu Power, IHI, Fukuoka Oxygen, ENEOS	Wind, solar PV, municipal waste power generation	Domestic low-carbon hydrogen supply chain Kitakyushu hydrogen town, hydrogen refuelling station		December 2020~

Note: HRS=Hydrogen Refueling Station; Hydrogen FC=Fuel Cell using pure hydrogen as input fuel; FCV=Fuel Cell Vehicle

(Source: MOE, n.d.)

3.2.3 Challenges and perspectives

Economic issues

Cost reduction of low-carbon hydrogen supply lies in the center of scaling up hydrogen application. Price target for low-carbon hydrogen supply is set at JPY 30/Nm^3-H_2 (around USD 3/kg-H_2) by 2030 and JPY 20/Nm^3-H_2 (around USD 2/kg-H_2) by 2050. However, in some cases the required price is even lower in the industry sector. For example, it is estimated that, for low-carbon hydrogen to be a competitive substitute of natural gas based hydrogen, its cost needs to be less than JPY 20-25/Nm^3-H_2 (USD 2-2.5/kg-H_2) (METI, 2020c). And for the Iron and Steel sector, in order to make hydrogen direct reduction produced pig iron to be competitive with conventional product, the cost of hydrogen would need to be less than JPY 8/Nm^3-H_2(around USD 0.8/kg-H_2).

In Japan, future hydrogen supply will come from two sources: hydrogen produced by domestic green power, and low-carbon hydrogen imported from overseas. For either case, the cost reduction is challenging. Renewable power generation cost in Japan is among the highest in the world, which means domestic green hydrogen production cost is also high. For example, according to International Energy Agency (IEA), renewable power generation cost needs to be less than 4 cents/kWh[13] (IEA, 2019) to make green hydrogen production cost below USD 3/kg (the government hydrogen supply price target for 2030). However, even the future purchasing price targets for solar PV and wind (onshore) in Japan set by the government are about two times of that level.

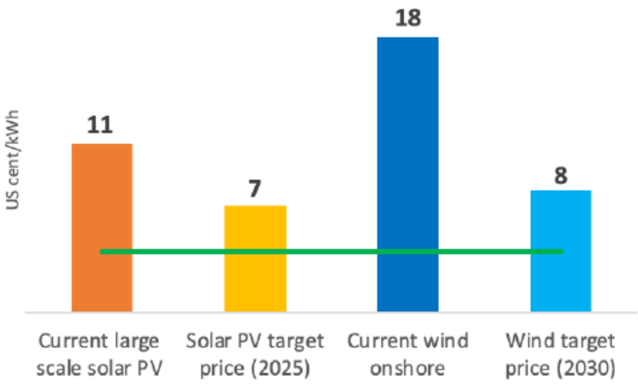

Figure 10: Renewable power price in Japan and the required renewable power price for green hydrogen to be competitive (based on METI, n.d.; METI, 2019a; METI, 2020a).

At the same time, although Japan has carried out several demonstration projects, international hydrogen supply chain has not been developed yet and drastic cost reduction is needed. For example, based on the current pilot project scale, cost associated with liquefied hydrogen transportation is estimated at around around USD 17.5/kg. To achieve the 2030's hydrogen supply price target the total transportation cost needs to be less than one tenth of the current level within the next decade. And to the cost reduction requires significant scaling up of the supply chain.

[13] Load hours 2000, CAPEX of electrolyzer USD 450/kW

Examples of scaling up hydrogen transportation chain

	Current pilot scale	Commercial scale
Hydrogen liquefaction	2 t/d	1,000 t/d (50 t/d * 20)
Tank at export terminal	2,500 m^3	200,000 m^3 (50,000 m^3 *4)
LH2 ship	1,250 m^3	320,000 m^3 (160,000 m^3 *2)

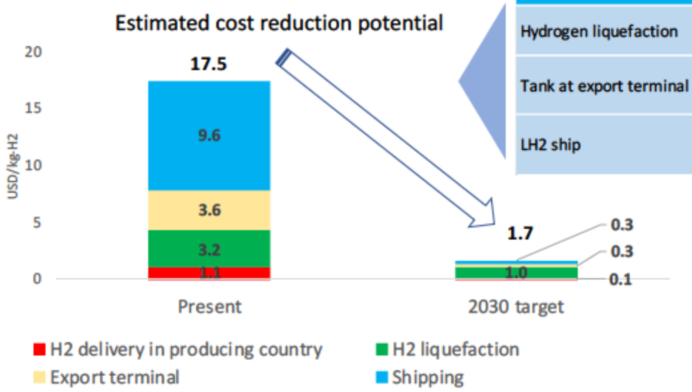

Figure 11: Cost reduction of liquefied hydrogen transportation (based on METI, 2020e).

Technological issues

Hydrogen used in the industry sector (refineries, petrochemical facilities, etc.) today is almost fossil fuel based. Some of the hydrogen is a byproduct from industry processes and the replacement of this hydrogen with low-carbon hydrogen will require changes to the process. However, the non-byproduct fossil fuel based hydrogen could be substituted by low-carbon hydrogen. For example, hydrogen consumption of Japan's biggest oil company, ENEOS, is around 6.6 billion Nm^3/year (around 0.6 million tons/year) in 2017, within which around 4.2 billion Nm^3/year (around 0.4 million tons/year) is byproduct from the refinery process and the remaining 2.4 billion Nm^3/year (around 0.2 million tons/year) is from outside of the process and can be replaced with low-carbon hydrogen (METI, 2020 c). It is estimated around 7.7 Nm^3/year (around 0.7 million tons/year) hydrogen demand in Japan's overall oil refineries could be replaced with low-carbon one by 2030 (METI, 2020c).

On the other hand, in the future, the Iron and Steel sector is supposed to be the largest industrial user of low-carbon hydrogen. As mentioned before, hydrogen's application in this sector is still at the research stage. Operation of the first prototype of the COURSE50 plant is expected to get started around 2030.

Other issues

Domestic infrastructure of hydrogen transportation and distribution will also be an important issue when the applications of hydrogen get further expanded. However, the natural gas pipeline in Japan is not as developed as that in Europe, and the discussion of converting current natural gas network to hydrogen transportation/distribution is at the very beginning stage (more details in the next chapter).

Furthermore, to facilitate low-carbon hydrogen's usage, clear ownership of its environment attribute will also be needed. This will require certificate of carbon footprint and origin of the low-carbon hydrogen. However, though there are some pilot projects on low-carbon hydrogen's certification system at the local level in Japan, there is still very little discussion at the national level.

3.3 Hydrogen natural gas blending

3.3.1 Strategy

In Japan's Hydrogen Strategy, there was little mention on hydrogen natural gas blend. Meanwhile, hydrogen natural gas blend is within the realm of policy discussions on decarbonization of the natural gas network. However, the discussions are still at the beginning stage. The Japan Gas Association envisioned that towards becoming carbon neutral by 2050, fossil fuel methane (natural gas) will be replaced by low-carbon gases including hydrogen, carbon neutral methane (low-carbon hydrogen methanation), and biogas. There is no pilot or demonstration project on hydrogen natural gas blend being used in the industrial sector in Japan at the moment.

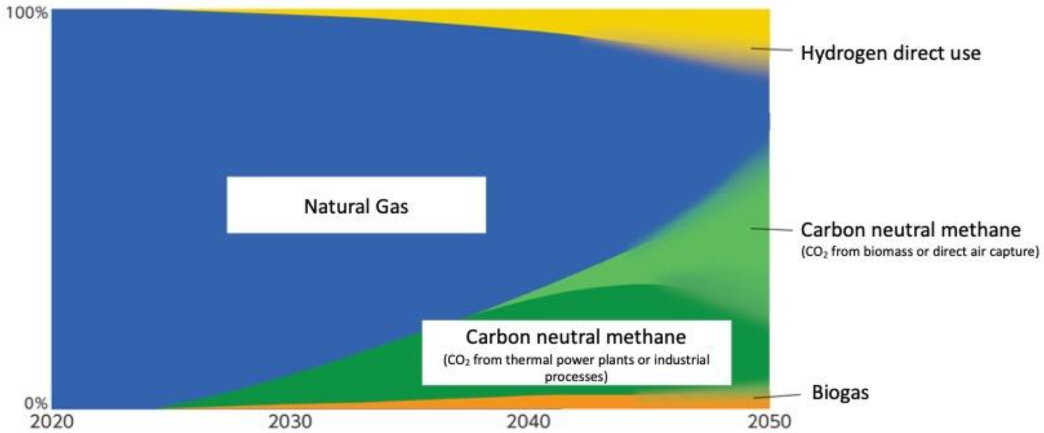

Figure 12: Gas Network's Decarbonization towards 2050 (based on Japan Gas Association, n.d.).

3.3.2 Challenges and perspectives

In Japan, technical readiness of natural gas pipelines for hydrogen blending is still mostly unknown. Hydrogen natural gas blend's impact on gas appliances, especially those which require strict heat control from certain industries, is one of the major concerns. In addition, hydrogen blending into natural gas may also affect some Enefarms' performance.

Meanwhile, discussions on the long-term strategy for decarbonization of the gas network system in Japan has just started. Lacking the clarity of the long-term policy strategy, the industry feels reluctant to make investment commitments. Furthermore, hydrogen is facing competition from other low-carbon gases such as biogas and carbon-neutral methane, which can be used with little technical changes to current infrastructure and gas appliances. The overall cost of hydrogen including fuel cost of hydrogen and the cost associated with infrastructure and appliances adaptation need to be competitive to other competing options. As mentioned before, hydrogen cost reduction for Japan is more challenging than other countries and this gives the gas utilities good reasons to have concerns on stable supply of low-cost hydrogen.

3.4 Carbon capture storage and utilization

3.4.1 Strategy

While carbon capture and storage (CCS) is recognized to have potential for substantial reductions of CO_2, carbon capture and utilization (CCU) has also gradually received attention as one of effective means to fight against climate change in Japan.

In parallel with commercialized CCU technologies which include enhanced oil recovery (EOR) and direct utilization of CO_2 such as welding and dry ice, Japan specifically focuses on “carbon recycling” which is a concept of using CO_2 as an input (Figure 13). In the carbon recycling system, CO_2 will be captured and then utilized to produce recycled materials and fuels by mineralization, artificial photosynthesis and methanation. Hence, utilizing recycled materials and fuels produced through the carbon recycling technology is expected to help the industrial process or transport sector to be decarbonized by replacing fossil fuels used conventionally before. Additionally, in case of Japan with heavy dependence on fossil fuel imports, the carbon recycling would enhance energy security since the new supply source for materials and fuels is secured domestically, which would consequently reduce the use of imported fossil fuels.

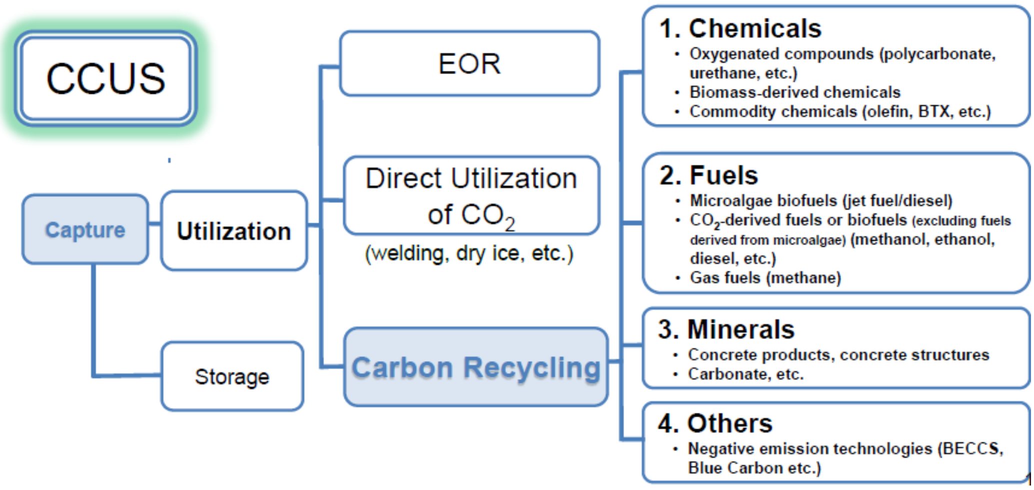

Figure 13: Concept of CCUS (Source: METI, 2019b, p.1).

The government of Japan gives principal support to CCUS technology development as it has been prioritized in the recent public policy domain. The 5th Strategic Energy Plan adopted in July 2018 aims for pursuit of all options regarding decarbonization technologies which cover hydrogen, CCS, and nuclear and renewable power, and collaboration on the development of these technologies through public-private cooperation (METI, 2018). CCS is also recognized as effective technology to reduce greenhouse gas emissions from the coal power plants, which will be included in the medium- and long-term power generation plan. Hence, with prospects for commercialization, the government directed a demonstration project of a whole CCS process from capture, through transportation, to injection and storage as illustrated in the next section.

The Long-term Strategy under the Paris Agreement approved by the cabinet in June 2019 identifies CCUS including carbon recycling as one of the key technologies to achieve the ultimate goal of a "decarbonized society[14]" (the Government of Japan, 2019). CCS and CCU are emphasized in the long-term vision and direction of policies and measures of the energy and industry sectors. For the energy sector, in the context of CO_2 emission reductions from the thermal power plants, the government aims to establish the first commercial-scale CCU technology by 2023 with a vision of deployment after 2030. The industry sector envisages utilization of low-carbon hydrogen and substitution by CCU, particularly carbon recycling, and biomass for fossil resources as feedstock in order to reduce CO_2 emissions from the manufacturing process.

In June 2019, the Roadmap for Carbon Recycling Technologies was published to show the path to commercialization of potential technologies in the three main areas of chemicals, fuels, and minerals (METI, 2019b). The carbon recycling technology is expected to encourage research and development (R&D) and innovation on CO_2 utilization through collaborations among industries, academia, and governments across the world. The roadmap presents technological challenges and the target by 2030 and 2050 onwards by technology. The short-term target covers technologies which will require no hydrogen, produce high-value added materials such as polycarbonate, bio-jet fuel, and road curb blocks, and are expected to be deployed around 2030. The long-term target after 2050 expects commercial deployment of high-demand commodities such as olefins and BTX (benzene, toluene, and xylene) on the condition that the hydrogen supply cost is decreased to JPY 20 (EUR 0.15)/Nm^3.

The roadmap is illustrated in the three phases (Figure 14). The Phase 1 up to 2030 pursues research, development and demonstration (RD&D) which will advance carbon recycling technologies. The Phase 2 (around 2030) aims to reduce costs of technologies targeted in the Phase 1 for commercialization and continues technology development and innovation to achieve the long-term target. In the Phase 3 (2050 onwards), products and technologies developed through the carbon recycling initiative are to be utilized widely at affordable costs.

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[14] The "decarbonized society" means "achieving a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century." (the Government of Japan, 2019)

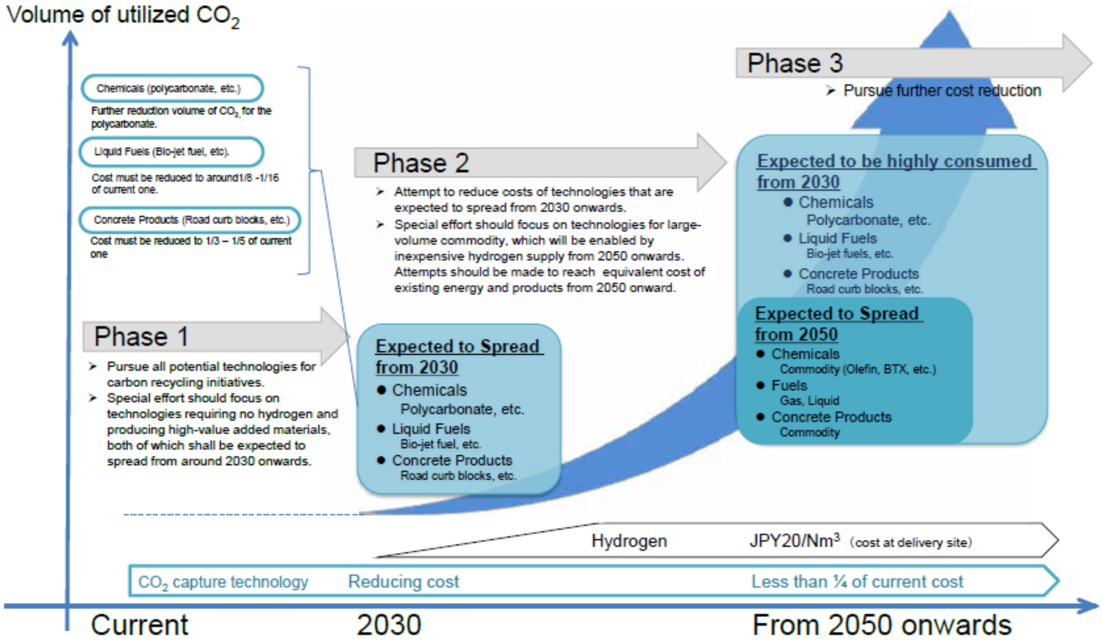

Figure 14: Carbon Recycling Roadmap (Source: METI, 2019b, p.2).

Based on the Long-term Strategy under the Paris Agreement and the Integrated Innovation Strategy 2020[15], the Environment Innovation Strategy was formulated in the fields of energy and environment in January 2020 (Cabinet Office, 2020). This strategy consists of the Innovation Action Plans, the Acceleration Plans, and the Zero-Emission Initiatives. The Innovation Action Plans put priority on the five areas in which the technology related to CCUS is included along with the other focuses (non-fossil fuel energy, energy network, hydrogen, and zero-emission agriculture, forestry and fishery). The second pillar of the strategy is the Acceleration Plans which develop various research frameworks and promote private investment to facilitate the Innovation Action Plans. For instance, the first Green Innovation Strategy Meeting which oversees inter-agency initiatives was held on July 2020 for the effective implementation of the R&D projects. In addition, Hiroshima-Osakikamijima Carbon Recycle Research, Development and Demonstration Base presented in the next section is supported within this framework. Lastly, the Zero-Emission Initiatives are collaborative works and outreach activities to share information and innovative technologies and strengthen international cooperation. Under this initiative, the Government of Japan hosted the International Conference on Carbon Recycling in two consecutive years 2019 and 2020.

[15] The Integrated Innovation Strategy is devised annually under the Science and Technology Basic Plan.

Carbon Recycling 3C Initiative was announced to accelerate innovation in light of the Roadmap for Carbon Recycling Technologies at the first conference.[16]

The latest policy development is the Green Growth Strategy that Japan revealed on December 2020 (METI, 2020f). This is an industrial policy to lead the challenging goal of achieving carbon neutrality by 2050. This strategy identifies 14 industries including carbon recycling as important areas that have potentials of green growth and are indispensable to reach the carbon neutrality goal by 2050, and specifies an action plan and a target for each area. The carbon recycling area specifically focuses on concrete, microalgae biofuel, plastics produced through artificial photosynthesis, and technology to capture CO_2 from air. The government will leverage various policy tools to promote the green growth, such as funding of JPY 2,000 billion (approximately EUR 15 billion) for technology development for the next decade, tax incentives and regulatory reforms (METI, 2021).

The private sector is also interested in development of carbon recycling technologies. In August 2019, the Carbon Recycling Fund Institute was established to accelerate innovation of carbon recycling technologies (Carbon Recycling Fund Institute, n.d.). As of December 2020, 64 companies or organizations and 12 individuals have a membership of the Institute. Since the carbon recycling technologies can be applied in many sectors, the members participate from a wide range of industries including chemicals, steel, construction materials, fuels, engineering, financial institutions, trading companies, and universities. In FY 2020, 12 research projects were selected for the research grants (METI and NEDO, 2020).

3.4.2 Snapshots on research, development & demonstration

(1) Tomakomai CCS demonstration project

Commissioned by METI and NEDO, Japan CCS Co., Ltd has conducted the first large scale CCS demonstration project in Tomakomai, Hokkaido, from FY 2012 to FY 2020. This demonstration project aimed to establish the first integrated CCS system in Japan from CO_2 capture to storage with commercial-scale facilities. CO_2 generated from a hydrogen production unit in the Idemitsu Kosan Hokkaido Refinery was captured. It also intended to prove safety and security of a whole CCS system and make the public informed and understood about this project through information disclosure and activities to enhance social

[16] The 3C of this initiative signifies three actions. First, "Caravan" (promotion of mutual exchange) presents to disseminate the importance of carbon recycling and share the progress of technology development through international conferences. Network development and information sharing are also included. Second, "Center of Research" (establishment of R&D and demonstration base) emphasizes on research of carbon recycling technologies and development of an environment for scale-up and commercialization. Third, "Collaboration" (promotion of international joint research) pursues enhanced collaboration among partners including industry, academia, and government and international joint research.

acceptance, while acquiring skills in operation of the CCS system to prepare for an opportunity when CCS is to be commercialized (METI, NEDO, and Japan CCS, 2020a).

Figure 15 shows how this CCS project was operated. A portion of PSA (Pressure Swing Absorption) off-gas containing about 52% of CO_2 generated from a hydrogen production unit of the refinery was transported by a 1.4 km pipeline to the facilities where CO_2 was captured. Then CO_2 is compressed, injected and stored 3-4km offshore in two sub-seabed reservoirs of different depth.

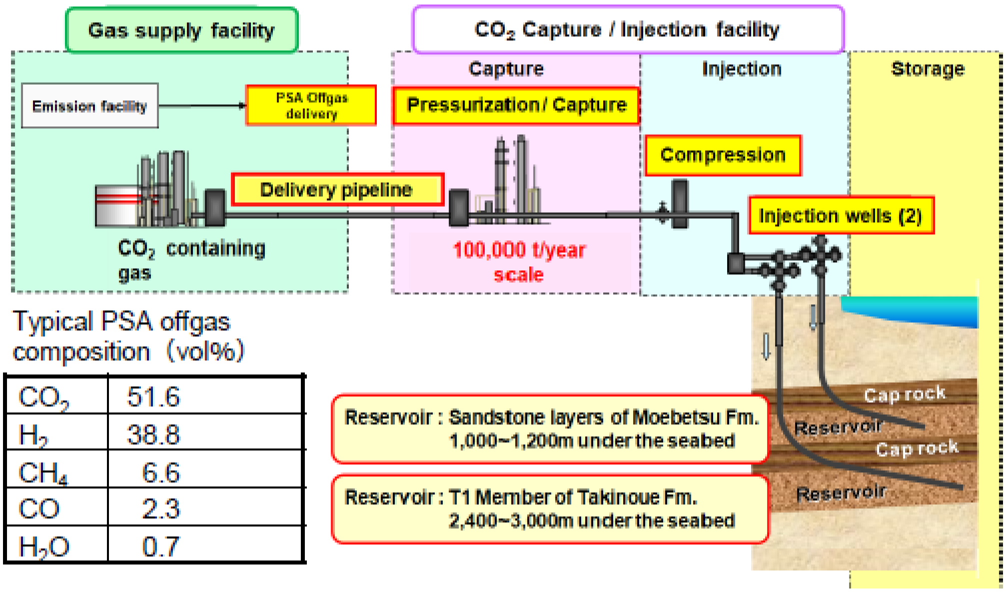

Figure 15: Tomakomai CCS demonstration project (Source: METI, NEDO, and Japan CCS, May 2020b).

The first four years were spent to prepare for the demonstration such as construction of facilities and drilling of injection wells. CO_2 injection started with the volume of 100,000 tonnes per year in April 2016 and reached the targeted amount of 300,000 tonnes in total in November, 2019 although the CO_2 injection took longer than the initially planned period of three years due to external factors. Data collected from monitoring showed no irregular change in pressure and temperature of the reservoirs, no indication of micro-seismicity or earthquake caused by CO_2 injection, and no CO_2 seepage. The marine environmental surveys did not find any indication of negative impacts like CO_2 leakage, either. Hence, the study result confirmed safety and security of the CO_2 injection and storage in the demonstration project.

While the monitoring of the CCS site will continuously be conducted, the study on CCS is also planned to overcome the obstacles and to enable the CCS system to be commercialized and scaled up. The subjects of the study include identification of suitable sites for CO_2 storage, technology development of long-distance CO_2 transportation, appropriate monitoring technologies and methods, and cost reductions. Furthermore, the CCS facilities in

Tomakomai will be utilized to study the effective use of the CO_2 captured such as the synthesis of basic substances (e.g. production of methanol).[17]

(2) Hiroshima-Osakikamijima Carbon Recycle Research, Development and Demonstration Base

Osakikamijima town, Hiroshima Prefecture, is designated to establish a carbon recycling RD&D hub. In this area, a demonstration project of an oxy-fuel integrated coal gasification combined cycle (IGCC) and an integrated coal gasification fuel cell combined cycle (IGFC), which is called the Osaki CoolGen project, has been carried out since FY 2012. After performance of oxy-fuel IGCC was tested in the first phase, the Osaki CoolGen project has moved to the second and third phases which handle the demonstration of oxy-fuel IGCC with CO_2 capture and IGFC with CO_2 capture, respectively (Osaki CoolGen Corporation, n.d.). Meanwhile, the carbon recycling RD&D hub intends to effectively utilize the CO_2 captured in the Osaki CoolGen project (Figure 16).

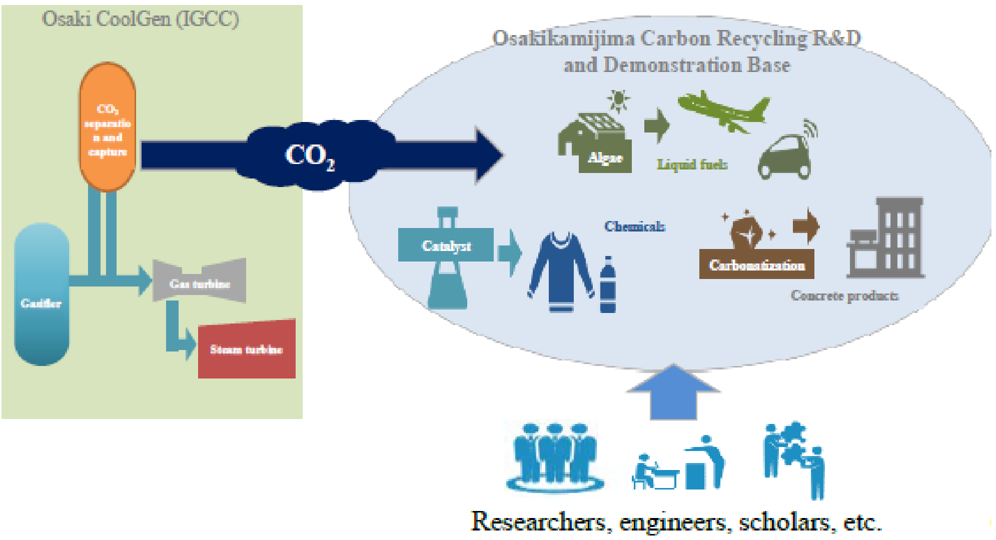

Figure 16: Schematic of Hiroshima-Osakikamijima Carbon Recycling RD&D Base (Source: Cabinet Office, 2020, p.69).

This carbon recycling RD&D hub is planned to have three areas. The 'basic research area' and 'demonstration research area' cover a wide range of R&D such as chemicals and minerals (concrete) whereas the 'algae research area' lays the foundation for research on microalgae (METI and NEDO, 2020). In August 2020, NEDO announced the funding of approximately JPY 6 billion (about EUR 46 million) for FY 2020-2024 to help the Osakikamijima carbon recycling RD&D base to be established for cross-cutting research and technology development in order to utilize CO_2 (NEDO, 2020b). Five projects are selected under the two themes. One subject is to develop facilities and infrastructure and assist management and research activities of

[17] To support the next phase of the facilities, the Tomakomai CCS Promotion Council was reorganized to the Tomakomai CCUS/Carbon Recycling Promotion Council in September 2020.

the research center. The other focuses on technology development on CO_2 utilization and assessment of commercial feasibility and effectiveness of carbon recycling technologies.

(3) CO2-SUICOM

A concrete product that utilizes CO_2 in the production process has already been commercialized in Japan. The product name is CO2-SUICOM, an acronym of CO_2-Storage Under Infrastructure by COncrete Materials (Yoshioka et. al., 2013).[18] Two distinctive measures in manufacturing this concrete enable CO_2 emission reductions (Figure 17). First, instead of cement, a special admixture (the γ phase of dicalcium silicate (γ-2CaO.SiO2), described as 'γ-C2S' hereafter) which has a lower level of CO_2emissions than cement is used for CO2-SUICOM. This special admixture γ-C2S helps concrete to be solidified by reacting to CO_2 and is made from a by-product such as slaked lime at chemical plants. In addition, coal ash can be a substitute for cement to produce this new concrete. Therefore, the process in which much of cement can be replaced by γ-C2S and coal ash contributes substantial reductions of CO_2 emitted from cement production. Second, CO_2 captured from exhaust gases of coal-fired power plants is utilized for carbonation curing of the concrete by making use of a feature of γ-C2S. As a result, not only coal ash but also CO_2 from the coal-fired power plants are utilized efficiently.

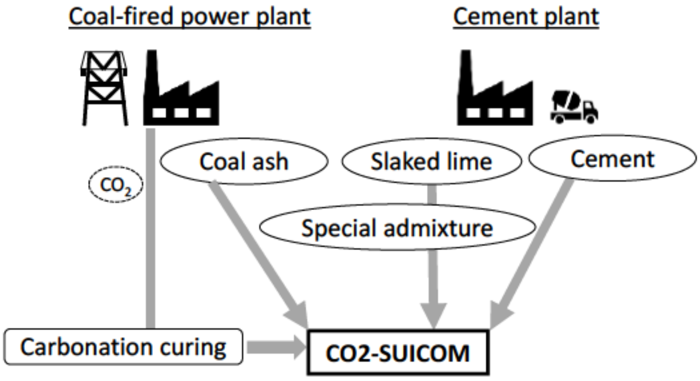

Figure 17: Schematic of CO2-SUICOM (based on Kajima Corporation, n.d.).

The estimation shows that these two processes result in substantial CO_2 emission reductions compared with that of ordinary concrete (Figure 18). Moreover, this concrete is able to resist efflorescence and abrasion as much as the ordinary one.

[18] The Chugoku Electric Power Co. Inc, Kajima Corporation and Denka Co., Ltd. jointly developed this technology.

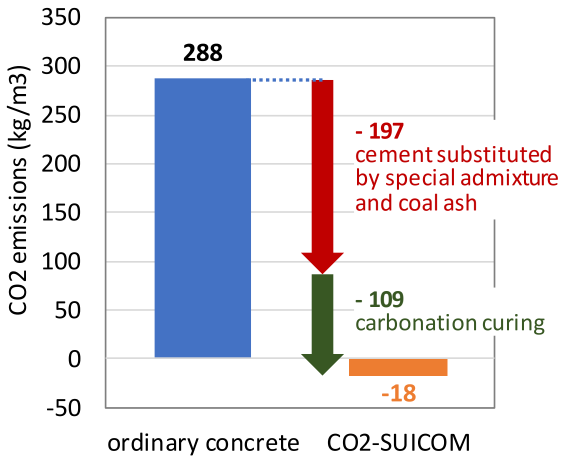

Figure 18: CO_2 emissions in concrete production (based on Kajima Corporation, n.d.).

Although this is available technology to reduce CO_2 emissions in the cement production, the special admixture and process make the production cost high. While CO2-SUICOM has been used in construction work as boundary blocks, foundation blocks, and paving blocks, it is difficult to apply to reinforced concrete and cast-in-place concrete (Challenge Zero, n.d.). Therefore, further technology development is necessary for cost reductions and wider applications.

(4) Technology Development for Para-xylene Production from CO_2

Assisted by NEDO, a group of a university and private companies launched a project named Technology Development for Para-xylene Production from CO_2 in July 2020 (HighChem et.al., 2020).[19] This project aims to improve the innovative catalyst for the production of para-xylene from CO_2, develop a method to mass-produce the catalyst and the process and design, and conduct feasibility study to prepare for the demonstration stage. Para-xylene is a basic compound in the production of PTA (pure terephthalic acid) which is a feedstock material for polyesters. This carbon recycling technology is expected to have economic and environmental advantages in that it can be produced with a relatively small amount of hydrogen while fixing a large amount of CO_2. This project will be conducted by FY 2023.

3.4.3 Challenges and perspectives

Economic issues

Commercial feasibility is one of the major difficulties that stand in the way of CCS deployment. While Japan has provided assistance towards RD&D on CCS technology, financial measures such as tax credits and subsidies are not put in place yet. For CO_2 storage, in general, if EOR

[19] University of Toyama, Chiyoda Corporation, Nippon Steel Engineering Co., Ltd., Nippon Steel Corporation, HighChem Company Limited, and Mitsubishi Corporation participate in the project.

is adopted, economics of CCS projects is likely to improve because it could generate revenues from oil production. As of 2019, CO_2 is injected and stored through EOR in 15 facilities out of 19 CCS large scale facilities (more than 400,000 tons of CO_2 captured per annum) in operation worldwide (Global CCS Institute, 2019). However, appropriate sites for CCS with EOR are likely to be limited. To relieve the economic constraints, financial measures are helpful to encourage CCS development. For instance, the United States, a pioneer of CCS, has provided not only financial supports for construction or operational costs of facilities but also tax credits.[20] These kinds of incentives will be required to make a CCS project feasible in Japan.

The CCUS technologies are not exceptional in that cost reductions are the hurdle to overcome just like other new technologies in the early stage of development. While chemicals and fuels produced from CO_2 through specific treatments are expected to be put in the market and yield revenues, they are not cost competitive due to the production process which keeps the products expensive. To make CCUS technologies competitive and affordable, it is critical to secure hydrogen at reasonable cost, ensure deeply decarbonized hydrogen, and reduce costs of the CO_2 sequestration and capture process.

Technological issues

As most CCUS technologies have not reached to the maturity levels, technology development and innovation need to be pursued to reduce costs and to make the technologies more applicable and available. As for CCS, technology development of capturing CO_2 will hold the key to lower costs since the cost of carbon capture process makes up the major part of overall CCS costs. The pre-combustion capture technology was adopted in the Tomakomai CCS demonstration project. The next challenge is to apply this technology to facilities where concentrations of CO_2 are lower at reasonable cost, which will pave the way for further deployment of the technology. For this application, hydrogen or ammonia production facilities and power plants with integrated coal gasification combined cycle are considered to have potentials.

To foster deployment of CCS, scaling up of a CO_2 storage capacity is necessary in Japan and technology enabling efficient operation of CO_2 injection and storage is vital for cost reductions. Japan also needs to establish safety and reliability of CO_2 storage technology in order to conduct a commercial CCS project and enhance public acceptance. There are risks of CO_2 leakage from the stored site underground and, in case of Japan, possible impacts to the CO_2 storage caused by earthquake have to be taken into consideration. To ensure safety of CO2 storage starts with appropriate storage site selection, which necessitates thorough

[20] In the United States, Section 45Q of Internal Revenue Code provides a tax credit on a per-ton basis for CO_2 sequestered. The tax credit is USD 35 per metric ton of CO_2 stored for EOR and USD 50 per metric ton for geologic storage by 2026 (US Department of Energy, 2019).

geological assessment. In addition, monitoring technology improvement is critical to detect CO_2 seepage in the subsurface and to collect data as accurate as possible for further study.

Although CCU technologies are expected to reduce CO_2 emissions, it is important to evaluate CO_2 emissions in the whole supply chain. It does not make sense if the amount of CO_2 emitted from the conversion process to chemicals and fuels is larger than the reduced volume of CO_2 through the CCU technologies. Since CO_2 is a stable molecule, substantial energy is required to split CO_2 and synthesize products from CO_2. Therefore, life cycle assessment (LCA) of the CCU technology is necessary to prove effectiveness of the technology. It is difficult to compare CO_2 emissions of chemicals and fuels produced by means of the carbon recycling technology since there are no consistent rules to evaluate CO_2 emissions based on LCA. Therefore, the carbon recycling technology necessitates development and establishment of rules which are approved internationally to measure CO_2 emissions based on LCA, since this is important to prove how much CO_2 emissions would be reduced in society overall. In addition, hydrogen used for this process should be carbon-free, that is, grey hydrogen derived from coal and natural gas are definitely not preferable.

RD&D on carbon recycling technologies are making progress and the following two cases present the recent development in Japan.

In October 2020, the first case of bio-energy with carbon capture has started operation in Fukuoka Prefecture (Toshiba Energy Systems & Solutions, 2020a). A large-scale carbon capture facility sequestrates more than 500 tons of CO_2 per day, which is more than 50% of daily emissions from the power plant with a capacity of 50MW. Fueled with palm kernel shells as the primary fuel source, this power plant is considered carbon-neutral.

Another new development is that six private companies reached an agreement to jointly develop fuel derived from CO_2 in December 2020 (Toshiba Energy Systems & Solutions, 2020b). These companies will review supply chains of sustainable aviation fuel (SAF) which is produced from CO_2 separated and captured from sources such as exhaust gases of industrial emitters, using technologies developed by Toshiba Corporate Research & Development Center which convert CO_2 to CO through electrolysis. This SAF will be supplied for flights in aviation, which will help decarbonize the aviation industry.

Infrastructural issues

Transport infrastructure is fundamental to deliver CO_2 that is captured at an industrial factory or a power plant to a permanent storage site or to a facility which produces chemicals or fuels. For CCU, hydrogen transport also needs dedicated infrastructure to a manufacturing place. Nevertheless, it is unlikely that the transport infrastructure of CO_2 and hydrogen would be developed when commercialization of CCUS is uncertain yet. Rather CO_2 infrastructure would work in the form of a natural monopoly where a single operator could bring benefits and efficiency to the market than multiple competitors due to high initial costs and economy of scale (IEA, 2020). In addition, there are risks of CO_2 leakage that will put an extra burden on the private sector. To assist the private sector who are interested in CCUS, the government could provide supports such as planning, financing and risk management related to CO_2. One possibility is that the government could plan to set up an industrial CCUS hub so that the private companies would benefit from economies of scale in capturing CO_2 with shared transport and storage infrastructure.

Japan needs more information and evaluation about different cases of CO_2 transport. The assessments conducted in the Tomakomai CCS demonstration project did not include the pipeline transport process. Large volumes of CO_2 could be transported either by pipeline or ship. If offshore CO_2 storage is planned in the future in Japan, both onshore transport and offshore infrastructures with regards to CO_2 transport and storage need to be considered. It is necessary to conduct more demonstration projects that deal with CO_2 transport by pipeline and ship under various conditions to collect data and information for evaluation.

Regulatory issues

Although CCS has been focused by the government of Japan, there are no specific rules applicable to a CCS project. The Tomakomai CCS demonstration project was conducted in compliance with the existing laws/regulations. In specific, the CO_2 capture facilities followed the High Pressure Gas Safety Act, the Industrial Safety and Health Act and the Gas Business Act while the Mining Act and the Mining Safety Act were applied to CO_2 injection and storage facilities and safety standards of the injection operation. The Act on Prevention of Marine Pollution and Maritime Disaster was applied to CO_2 storage in the subsurface and the marine environmental surveys.

However, these regulations do not cover some issues about the demonstration project extensively. For instance, the Act on Prevention of Marine Pollution and Maritime Disaster allows the chemical absorption using amine-based solvents only as the carbon capture technology in the subsurface (Research Institute of Innovative Technology for the Earth, 2020). Other CO_2 capture technologies which can be applied in the sub-seabed are not approved within the current legal system in Japan as they are still in the early adoption stage and there are not enough scientific data and information for validation. This implies that law amendment or new regulation will be necessary if CO_2 is captured by other technologies such as physical separation and membrane separation for injection and storage in the sub-seabed. Also, the demonstration project found that some indicators based on the Act were not effective to detect CO_2 leakage in the marine environmental surveys.

Furthermore, one of the important legal aspects with regards to the CCS project is absent in the existing legal context. In other words, long-term liability for a storage site and stored CO_2 and transfers of liability are not specified in the current regulatory framework in Japan. In general, long-term liability refers "any liabilities arising after the permanent cessation of CO_2 injection and active monitoring of the site" and an issue in question is centered on "whether responsibility for liabilities associated with a storage site should be transferred to government or retained by operators indefinitely" (IEA, 2011). It is difficult to prove that CO_2 stored underground will not be leaked in the very long-term even though it is possible to contain CO_2 in the subsurface completely for a foreseeable future. Therefore, it is vital to clarify who will be held liable and clearly stipulate certain requirements or conditions if responsibility for liabilities are transferred to the government at some point. There is one more issue identified in CO_2 storage of the demonstration project, which is lack of rules about subsurface access rights. To define where subsurface access rights belong will be necessary for drilling of injection wells and CO_2 storage.

Acceptance issues

Public acceptance is a necessary condition to implement a CCS project. In spite of the CCS demonstration project backed by the government and its high potential to reduce CO_2 emissions, it seems that the level of awareness and knowledge about CCS has been low in Japan. The questionnaire surveys which were conducted in 2010, 2013 and 2015 found that public acknowledgement about CCS had remained low (Kubota, 2016). In a question about the CCS technology in the 2016 survey, the share of the respondents who answered "know about CCS" or "know about it well enough to explain to the others" was merely 8.1%, whereas those who had never been aware or heard of it accounted for 55.1%, and those who had heard of the word "CCS" made up 36.8%[21]. The study also revealed that even those who thought that they knew about CCS did not understand correctly what the CCS technology was. The Tomakomai CCS demonstration project had attempted various activities to improve public awareness such as site tours, publications, lectures at school or forum, and events for children throughout the project period. Still it was not enough for CCS to be properly understood nationwide. Lack of information is an obstacle to transparency and accountability of the CCS project, making it more difficult for the public to make a decision whether or not to accept the CCS project. Therefore, public awareness about CCS needs to be enhanced by providing correct information through various tools.

4 Comparison of strategies, activities, and perspectives

In Germany and Japan, the basic materials industries are relevant economic sectors resulting in significant shares of greenhouse gas emissions. Almost 37% and 39% of total emissions in the country come from the German and Japanese industry, respectively, to which basic materials industry contributes relatively large shares. In Germany, industry emissions split into direct emissions (around 22%) and indirect emissions (below 15%); the latter being accounted to the energy sector. Industrial direct emissions are mostly energy-related (68%) with process-related emissions being at around 32%. In Japan, 90% of industry emissions are energy-related. Hence, decarbonising these sectors is particularly relevant to achieve carbon neutrality by 2050. However, neither Japan nor Germany have favorable conditions to

[21] The number of respondents were 3,912.

generate renewable energy on a large scale domestically. This exacerbates the decarbonization of the industry sector as relevant options discussed in this study would require green electricity as energy input, either for direct use, for producing hydrogen or for removing CO2 from industrial plants. Clean hydrogen is the other form of energy or raw material needed in large quantities for decarbonizing industry, as discussed in this study.

Regarding **direct use of hydrogen**, Japan's hydrogen strategy, published a few years ago, has so far focused on power generation, transport/FCV and Enefarms, its role for decarbonizing industry recently receives more and more attention, e.g. as part of Japan's Green Growth Strategy. Policy focuses on facilitating RD&D and improving investment environment through various policy tools such as funding, tax incentives, and regulatory reforms.

Germany has only recently published a relatively comprehensive strategy on hydrogen (NHS), which prioritizes the role of industry for creating demand for the hydrogen. Hydrogen should be green with priority, but blue hydrogen is acknowledged as a transitory solution too. While the NHS includes expansion targets for installing electrolyzers in Germany, natural gas is seen as a bridge for the transition by some. The NHS has installed a steering committee, which supports hydrogen developments in Germany, and sketches policy instruments that facilitate the application of hydrogen in the industrial sector. Policy discussions also revolve around the support needed by the industry for achieving carbon neutrality in the next decades and around hydrogen transport as well as ideal production locations. Germany is more advanced in large-scale RD&D projects for the direct use of hydrogen in the refinery, chemical and steel industries. In contrast, demonstration projects on large-scale direct use of hydrogen are limited in the industry sector in Japan, and small-scale projects of hydrogen applications focus more on the transport and residential/commercial sectors in local communities.

For both countries, scenarios suggest an enormous demand for hydrogen in industry. However, costs for domestic production and for (ship) imports will remain a key challenge. From a technological perspective, the two countries are also likely to face the problem that hydrogen direct-use will require adjustments in manufacturing processes.

The **blending of hydrogen with natural gas** is approached differently by each country. It is less discussed in Japan, also due to the lack of a comprehensive gas network like in Germany. While sensitive users in both countries fear blending (due to its negative impacts on industrial applications and product quality), Japan seeks to decarbonize the natural gas network by phasing in other low carbon gases like carbon neutral methane. Moreover, Japan needs further discussion to clarify the long-term strategy on how decarbonization of the gas infrastructure will be pursued in accordance with future gas demand structure and anticipated commercial benefits or costs.

In contrast to that, blending hydrogen with natural gas is somewhat more prominently discussed in Germany, particularly by the natural gas supply industry, and research takes up technological challenges. However, the phasing in of (green) hydrogen into the German gas network is not uncontested. Industry argues that pure hydrogen is more or less their only option to become carbon neutral, whereas other sectors (which would benefit from blended gas admixtures, like heat and buildings) have better options, such as direct electrification. Still, RD&D projects on blending hydrogen with natural gas are limited by number and scale even in Germany, and a transnational transport infrastructure for either pure hydrogen or natural gas blended with hydrogen will necessitate harmonized rules in relevant European countries.

CCUS also shows a contrast between Germany and Japan in terms of the focus by government. In Japan, CCUS is highlighted as one of the technologies to promote decarbonization in several policies such as the Environment Innovation Strategy and the Green Growth Strategy. It is also part of Japan's long-term vision of a decarbonized society and, thus, considered a central part in achieving climate neutrality by 2050. As regards CCS, the technology was demonstrated with offshore storage capacity of the targeted amount of 300,000 tons in total and will be continuously monitored and studied for future policy direction. Public awareness of CCS needs to be raised although hardly any public skepticism has emerged so far. The country's CCU strategy focuses until 2030 on products and materials that do not require hydrogen as an input, due to the limited availability and high costs of the gas. In order to turn CCU into a commercial business case, the Japanese Government has set up the Carbon Recycling R&D Hub and facilitated RD&D projects mainly through financial support.

In Germany, CCUS does not currently enjoy a technology-focused strategy as much as hydrogen does. CCS technology is seen as an important option to decarbonize industry, particularly in the cement industry. However, onshore storage will not be realized in the near future due to unknown impacts (e.g. on groundwater) and public concerns, which is why debates focus on offshore storage with partners such as Norway. As regards carbon utilization, several large-scale demonstration activities are successfully carried out. Still, there are several issues to reflect upon including the product type, in which the removed CO2 is fed in, and the durability of storing carbon away from the atmosphere in it.

Since CCU technologies are at the early stage of development, there are some issues that both countries would need to cope with in common. For instance, life cycle assessment will be critical to see the environmental impact of CCU, because substantial energy is required in the CCU process, and because the durability of removing carbon from the atmosphere may need assessment. Development of a CO_2 transport infrastructure will also be difficult due to uncertain business perspectives without a clear long-term planning of the government. Furthermore, an adequate regulatory framework will be necessary to ensure safety concerning CO_2 transport and storage.

5 Recommendations for a way forward

5.1 Recommendations for Germany

5.1.1 Hydrogen direct-use

The NHS and RD&D activities show the Government's will to facilitate hydrogen production and application in the industry sector, even though some would have wished for a more ambitious electrolyzer expansion (VDMA, 2020). Refineries appear to be the industrial first-movers for taking up hydrogen, which is also acknowledged by the fact that 40% of Germany's new electrolyzer capacity are planned as part of refineries. Several new projects in the chemical and steel industry will be realized in the years to come. For steel, DRI-technology is demonstrated with Germany's main steel producers. Most demonstration cases go hand in hand with rather small-scale electrolyzers being developed, at first, and results feed into the scaling up of larger electrolyzer designs. This can be seen as a step-wise approach to derive learning effects.

The Government expects newly developed domestic electrolyzer capacity to meet only 12 to 16% of hydrogen demand in 2030. Due to the overall focus on green hydrogen, it becomes crucial to increase the pace for finding additional green solutions. The newly established hydrogen steering committee will have to take on this task balancing supply and demand from various sectors, especially for green hydrogen. In order to safeguard imports, which can be considered an important tool to meet hydrogen demand, the thinking together of the international dimensions of the EU's and Germany's strategy might be mutually beneficial.

In Germany, new hydrogen production goes hand in hand with additional renewable electricity. Most industrial demonstration projects include renewable electricity capacities, but natural gas seems to be part of the solution, at least, to bridge the transition period in the steel sector. Hence, the future role of gas deserves substantial attention, particularly its phase out. Apart from that, infrastructural elements are an integral part of such projects, not least because the transport infrastructure for pure hydrogen in Germany is very limited so far. Rough scenarios to concretize infrastructure planning exist (Federal Network Agency, 2020; FNB Gas, 2020) but efforts must be stepped up and become politically legitimated in order to safeguard investment security for hydrogen producers, users and transport operators.

Some policy support exists for industrial hydrogen users. However, given the global market in which most companies of basic materials industry operate, it requires the orchestration of policy revisions and new instruments to be designed so that, ultimately, climate friendly products become competitive. This includes instruments such as CCfD and a Carbon Border Adjustment mechanism, amongst others (Agora Energiewende & Wuppertal Institut, 2019; Leipprand et al., 2020). Germany's NHS and the Government's Recovery Package give an opportunity to ramp up hydrogen production and use and to facilitate RD&D. Bringing down costs of electrolyzers and energy inputs needed for hydrogen production, transport technology and industrial upgrades will have to be on the Government's agenda.

5.1.2 Hydrogen natural gas blending

The Government and, most likely, the hydrogen steering committee established through the NHS will have to balance the existing positions on HNG admixtures. If hydrogen concentrations in HNG increase, several questions will arise for both infrastructure operators and sensitive industrial applications, amongst others. In the end, higher concentrations come at a cost and it is open who will bear them to finance technology upgrades. European cooperation and coordination is as important as for the development of a pure hydrogen pipeline infrastructure. Despite controversies on blending hydrogen with natural gas, there are projects, which investigate upon the implications of HNG admixtures and offer solutions for increased hydrogen concentrations.

5.1.3 Carbon capture storage and utilization

While it would go beyond the scope of this paper to neatly discuss alternative pathways in certain industries, some deserve to be mentioned in order to balance decision making in a broader context. For instance, in the construction sector, alternatives to steel and cement can be wood (also storing CO_2 naturally) or lay. Apart from that, (re-)circulation of materials such as steel, aluminium and plastics can bring enormous emissions savings. Literature suggests that 75%, 50% and 56% of demand in steel, aluminium and plastics could be meet by recirculated materials (Agora Energiewende & Wuppertal Institut, 2019; Churkina et al., 2020; Material Economics, 2019; Robbins, 2019).

If focusing on CCUS for industry, the discussion can be divided into a few supplementary elements. Due to low acceptance among the German population resulting from onshore demonstration projects for power plants, CCS faces a contested socio-political environment. However, the move to turn to offshore storage as well as using CCS for process-related industrial emissions has apparently reduced public headwinds and increased stakeholder support even from some environmental groups. Relevant legal issues hindering the cross-border transport of CO_2 for offshore storage have been overcome. Given that countries such as Norway seek to store CO_2 underneath the sea shows that the technology is available in principle, even though at higher prices in comparison to onshore storage. Questions for policy makers will also focus on CO_2 transport and (offshore storage) costs, for which solutions are about to be sought with European partners.

Public debates on CCU are less emotional. Some oppose the idea of utilizing industrial emissions and favor technology options such as direct air capture, but, in fact, the amount of heavily funded demonstration projects (e.g. Carbon2Chem, Rheticus) shows that Government sees industry as both a raw material provider and user of CO_2. In the German CCU discussion and RD&D projects, the chemical industry, refineries and cement producers become CO_2 sinks, even though the role of CCU for synthetic fuels (and also for fertilizer production) is not undisputed due to its low / short storage capacity/ service life. In this respect, the process of carbonation, in which CO_2 can be made use of in building materials, is seen as a promising option to store CO_2 permanently, but RD&D needs to push for a valid business case. The limited amount of industry clusters with capacities for cross-industrial business models will have to be explored with priority.

In parallel to that, infrastructural questions will become more and more relevant for CCU connecting supply and demand. However, a physical infrastructure raises fears of lock-in effects keeping CO_2-based business models alive, which must be addressed by long-term policy roadmaps, if large-scale quantities of CO_2 are supposed to be captured. Competitive renewable electricity must accompany a sustainable CCU pathway, along with cross-infrastructural planning connecting power, hydrogen and CO_2 production with (geographically rather diverse) demand centers.

An overall strategy on CCUS may provide a better picture of the role of CCS and CCU in the future and may provide planning security. This would also acknowledge the long lead-times the technology needs to be set up. The national hydrogen committee will play a role for integrating CCU-related developments into hydrogen deployment policy. The institutional development of a market facilitator may overcome some investment restraints. However, the open questions regarding the real contribution of CCU to reducing GHG emissions (especially in comparison with alternatives) and its durability need to first be solved with priority, before embarking on a strong CCUS strategy.

5.2 Recommendations for Japan

5.2.1 Hydrogen direct use

The 6th Strategic Energy Plan is expected to be published in the summer of 2021. After the publication of the Strategic Energy Plan, Japan's hydrogen strategy will also be revised. As mentioned before, in the previous Hydrogen Strategy, hydrogen's application in the industry sector was not mentioned much. More government support and public private partnership on industry's hydrogen use can be expected in the future.

Cost of hydrogen supply is the most important issue. To bring down domestic green hydrogen cost, further efforts on cost reduction of solar PV and onshore wind, as well as accelerating the development of offshore wind will be needed. Furthermore, given the mismatch of the location of hydrogen demand and renewable resources, and for the purpose to improve the capacity factor of water electrolysis units, using grid electricity combined with renewable energy credits could also be an option worthy of more attention and discussion.

To facilitate the development of an international hydrogen supply chain, in addition to accelerating the efforts on scaling-up and cost reduction of the equipment, an internationally agreed low-carbon hydrogen standard and certification will also be needed. It is also necessary to reinforce international coordination and collaboration on low-carbon hydrogen certification for more study and discussion on this issue.

To realize hydrogen use in the industrial sector, a domestic hydrogen-dedicated transport and distribution infrastructure is required, as hydrogen blending into the existing natural gas network is considered as an option that raises a number of challenges (See below). Further studies to figure out the industrial areas which are suitable for developing new hydrogen-dedicated infrastructure rather than hydrogen blending are needed.

5.2.2 Hydrogen natural gas blending

To facilitate hydrogen natural gas blend in Japan, commitment from the government, gas utility companies, as well as cooperation from gas appliances manufactures and gas consumers are necessary. As a first step, the government and gas utilities together with other stakeholders need to work together to draw a clear picture and strategy on how to decarbonize Japan's natural gas network and bring clarity to hydrogen's role in it. Meanwhile, to help policy makers and the industry make their decision, further study on natural gas pipeline's readiness for hydrogen blending is needed. In the short term, the role of government is important. This includes development of a long-term national strategy and support of technical and feasibility studies and pilot projects. In the medium- to long-term, though the industry will be the main player, the government's support on safety standard regulation and price mechanism will still be critical.

5.2.3 Carbon capture storage and utilization

The CCUS technologies involve potentials of CO_2 reductions and may help the economy in terms of competitiveness and growth in the future if technology development is successfully conducted. The government plays a critical role to cope with challenging issues related to the CCUS technologies which are at the early stage of development. Especially, the public support is essential in the areas where the private sector would not see a rationale for investment due to high upfront costs and uncertain commercial feasibility given unclear foreseeability. It is ideal that synergies would be created from collaboration among the government, industry, and academia.

First of all, continuous financial support for RD&D will buttress the foundation for the technology application and commercialization. Innovative ability and perspectives of the private sector and academia need to be utilized with the public funding. Secondly, the public support will help the shared infrastructure of CO_2 transport and storage to be realized in case investment in the infrastructure is not pursued by the private sector alone. Thirdly, since the CCUS technologies are long-term projects, practical planning and strategies presented by the government will be a good guidance for the private sector where they should be headed for.

Following changes or development of the market, however, the government may be required for flexible adjustment in management.

Carbon pricing systems are regarded as one of effective market-based tools to encourage the industry sector to work on CO_2 reduction efforts. As suggested in the Green Growth Strategy, discussion on carbon pricing mechanisms has just started in the committee established by the government of Japan. Revision of the current regulatory framework or introduction of a new measure regarding carbon pricing arrangements will be deliberated to make it more effective to contribute to economic growth. Policy design needs to be carefully balanced between keeping competitiveness of the industry sector and accelerating deployment of the CCUS technologies.

Lastly, Japan proposed the establishment of an Asia CCUS Network at the East Asia Summit Energy Ministers Meeting in November 2020 (METI, 2020 d)[22]. This platform aims to share information on the development of the business and regulatory environment and the best use of CCUS among the participating countries. Such international cooperation will facilitate clean transition beyond national borders and a fair and transparent market for CCUS in the future.

6 Recommendations for cooperation

Chapter 3 has discussed both existing RD&D projects and challenges and perspectives for the three ways that have potential for contributing to the decarbonization of energy-intensive industries. Particularly direct hydrogen use and CCU may hold large potential for further joint RD&D between both countries. For example, at a recent event, Chiyoda corporation expressed its interested to cooperate with European companies in the further development and testing of its technology to catalyze para-xylene, a basis for polyester production, from hydrogen and CO_2. At the same time, the challenges discussed in chapter 3 need to be addressed by RD&D, for example on costs, technologies, regulation, and what is actually the potential for reducing GHG emissions, particularly for some CCU options.

As regards policy instruments and policy mixes, several aspects are to be acknowledged on the German and European side. For instance, CCfD are developed in Germany, in order to financially support higher OPEX resulting from the application of breakthrough technologies and green hydrogen. Moreover, a Carbon Border Adjustment Mechanism might be implemented at the EU level in order to create a level playing field between domestic and non-EU industries and to accelerate a transition of basic material industries beyond EU territory. These and other policy discussions in the EU and Germany can be systematically be processed to draw lessons learned for Japan. Likewise, lessons from the orchestration of

[22] Energy ministers from Japan, China, South Korea, 10 ASEAN member states, Australia, India, New Zealand, Russia, and the United States participated in the online meeting.

policy instruments in Japans might provide interesting insights for German and European stakeholders. As basic material industry, in general, faces global competition, higher costs for decarbonizing intermediate products like steel, cement and chemicals should also be reflected upon how to create green lead markets, which might include instruments such as green public procurement of respective products. Therefore, a societal lens is necessary in order to not overburden low-income households.

In this respect, other pathways (complementary to those focused on in this study) may also deserve mutual attention such as increasing circularity, mitigating resource demands and strengthening energy efficiency. For instance, as regards societal acceptance, results from Japan's CCS projects and environmental impacts appear to be relevant for Germany and internationally.

Another possible area for cooperation is to facilitate development of the international sustainability and safety standards regarding hydrogen production and transport (cf. Shibata et al 2020). Such international standards will be essential for hydrogen to level the playing field as well as to ensure safety which is critical to improve public acceptance. Germany is expected to play an important role and make the best use of knowledge and experiences gained through the CertifHy initiative, but certification of clean hydrogen should build on more comprehensive criteria than CertifHy (Shibata et al 2020). For Japan where a hydrogen certification scheme is not on the table at the national level, it will be a good opportunity to establish national rules consistent with the international standards. Collaboration between the two countries could lead to create a fair and environment-friendly framework for decarbonized materials.

7 Concluding remarks

This report explored policy directions and possible technologies to decarbonize the industry sector in Germany and Japan, because it would be difficult for both countries to achieve the carbon neutrality by 2050 without the sector's efforts of reducing CO_2. In particular, hydrogen direct use, blending hydrogen with natural gas, and CCUS were raised as the subjects to be studied.

Both Germany and Japan have set the policy framework to encourage hydrogen utilization in the industry sector and provided assistance to expedite the RD&D projects covering the hydrogen supply chain. Given the current technology available and technology development perspectives, some energy-intensive industry sectors do not have many choices but hydrogen which is considered an enabler for decarbonization. Still, production costs need to be reduced for hydrogen to be applied in the industry sector. Hence, further RD&D is necessary to advance technology. For instance, the capacity of electrolyzers will be scaled up to the extent that economies of scale work through technological innovation, consequently leading to cost reductions. For both countries, green hydrogen is certainly desirable but blue hydrogen is also in consideration until green hydrogen becomes available at affordable costs.

On the other hand, it seems that Germany and Japan have different stances on blending hydrogen with natural gas and on CCUS. With the extensive natural gas pipeline network, blending hydrogen with natural gas is an opportunity for Germany to make use of the existing infrastructure although there are alternative options to replace natural gas, which may be more energy-efficient and cost-effective, and various issues need to be overcome before it is actually put in place. However, Japan may stand back from this area due to lack of adequate natural gas infrastructure and proper technology, and uncertain commercial feasibility unless the government or the industry is engaged with discussion on the long-term planning. Rather, Japan currently seems to be more interested in deployment of CCUS technologies compared with Germany, where there are a number of pilot projects too, but no strategy as for hydrogen yet. While different circumstances result in diversification of policy directions that the two countries would choose, a fundamental idea is to seek best options which will be technologically available and affordable to keep the competitiveness of the industry sector. Since these technologies are still in the experimental or demonstration phase, it is interesting to see how these technologies will be developed and applied in each country.

Although many obstacles are observed in the above-mentioned technologies, i.e., hydrogen direct use, blending hydrogen with natural gas and CCUS, they will certainly present potentials to abate CO_2 emissions, if a consistent life-cycle approach is taken. Not only Germany and Japan but also the world unexceptionally needs technologies to decarbonize the industry sector to deal with the climate change issues. Hopefully, further collaboration between Germany and Japan will lead and accelerate technology development at global level.

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付録４．新型コロナウィルス後のエネルギー／気候政策

GJETC: Energy / Climate policy in the post COVID-19 era

Ichiro Kutani, Peter Hennicke, Naomi Gericke, Fiona Bunge

Content

1. Introduction

The corona pandemic has highlighted previously existing economic, social and cultural weaknesses or strengths, contradictions of interests and inequalities worldwide like in a magnifying glass and with great speed. It is the world event in peacetime since the 1930s, which - even more profound than the world financial crisis of 2008/2009 - has brought the global systemic interrelationships and vulnerability of the "One World" into the everyday consciousness of the world community. At the same time, warnings were given during the pandemic and in connection with the huge global recovery programs not to postpone the fight against other urgent crises such as climate change. Instead, integrated strategies are necessary in order to protect against the pandemic and achieve an economic recovery, more sustainable economic development and ambitious climate protection at the same time with the recovery programs

At the "Climate Ambition Summit" (12 December 2020) UN Secretary General Antonio Guterres delivered an alarming speech[1] which urgently called for highest climate mitigation ambition of all worldwide recovery packages. This is a serious wake up call for all countries including Germany and Japan: "The recovery from COVID-19 presents an opportunity to set our economies and societies on a green path in line with the 2030 Agenda for Sustainable Development. But that is not yet happening. So far, the members of the G20 are spending 50 per cent more in their stimulus and rescue packages on sectors linked to fossil fuel production and consumption, than on low-carbon energy. This is unacceptable. The trillions of dollars needed for COVID recovery is money that we are borrowing from future generations. This is a moral test. We cannot use these resources to lock in policies

[1] https://www.un.org/sg/en/content/sg/statement/2020-12-12/secretary-generals-remarks-the-climate-ambition-summit-bilingual-delivered-scroll-down-for-all-english-version

that burden future generations with a mountain of debt on a broken planet.“ (Antonio Guterres 2020)

The IEA[2] demands as well that the huge global stimulus programs should be used as an opportunity to initiate a more ambitious economic structural change in the direction of sustainability and climate protection. Thus there is a growing fundamental consensus worldwide that after the Corona pandemic the “New Normal” cannot remain the “Old Normal”. According to Albert Einstein's famous sentence: "Problems cannot be solved with the same way of thinking that created them".

At the time this short study was prepared (12/2020), most countries worldwide were in a second wave of the Corona pandemic. In this respect, it is still too early to attempt a final assessment of the effects of the pandemic on the energy system. It surely entails new risks, but also opportunities. Both directions have been vividly discussed. Voices pointing to *potential chances* of the crisis, are seeing a change in policy style from a (neoliberal) "Night Watchman State" to a (keynesian) "Shaping State", are hoping for an accelerated green structural change through recovery programs and value chains becoming more deglobalized and resilient. A potential re-evaluation of system-relevant work, reduced working hours and adjusted wage levels, and chances to induce more justice through ecological and social tax reforms are being discussed. These voices also underline the chances for a sustainable transformation of the mobility sector with soft tourism and less air and cruise travel, expanded bicycle infrastructure and fewer commuters due to more home office, less business trips and more ViCos.

Other voices fear social insurance and wage cuts to refinance public debt - reluctance to (pre-)finance the energy transition and sustainable development or

[2] e.g. IEA https://www.iea.org/reports/sustainable-recovery

rising unemployment and poverty, especially in the global South. They expect less diversity in trade (Internet), culture, sports, international exchange and an enforced two-tier health and care system. They point to even larger ‘ecological rucksacks‘ of digitalization (electricity/resource consumption) and warn that the pandemic, also in the transport sector, could have rather opposite effects with even more individual automobility to be expected instead of public mobility (rail, public transport). All of this resulting in less intergenerational justice and international solidarity.

Thus, there is a high level of uncertainty about what are temporary effects and what new trends permanently triggered by the corona pandemic will come up. It is also interesting to compare possible different effects of the Corona pandemic in Japan and Germany not only in terms of the scope and structure of the state recovery programs, but also in terms of political and socio-ecological effects.

This short and preliminary study tries to identify possible impacts of COVID-19 on the economy and related energy consumption/CO_2-emissions and on possible induced long term structural and behavior changes. It analyzes the recovery programs and their possible impacts on sustainable structural change and on the style of policy making. Finally, it suggests to set up a more comprehensive German-Japanese research project that compares the longrun effects of the Corona crisis for both countries.

In any case, it is already clear that the pandemic has a profound impact on all energy-related social activities, especially in transport and the international division of labor, but also in the organization of work, in the use of digitization, in energy-related behavioral trends and - in particular in Europe - regarding the role of the state (“political style”). In this respect, the post-corona period will bring both new opportunities and new risks for the transformation of the energy system and the decarbonisation of the economy, which will require closer examination.

2. Socioeconomic impacts and related energy consumption and CO_2 emissions

The effects on the economy and related energy consumption and CO_2 emissions worldwide and in both countries in 2020 and 2021 are challenging. Economy slows in every part of the world. This entails new risks, but also opportunities to steer the economic development towards more sustainability and climate protection.

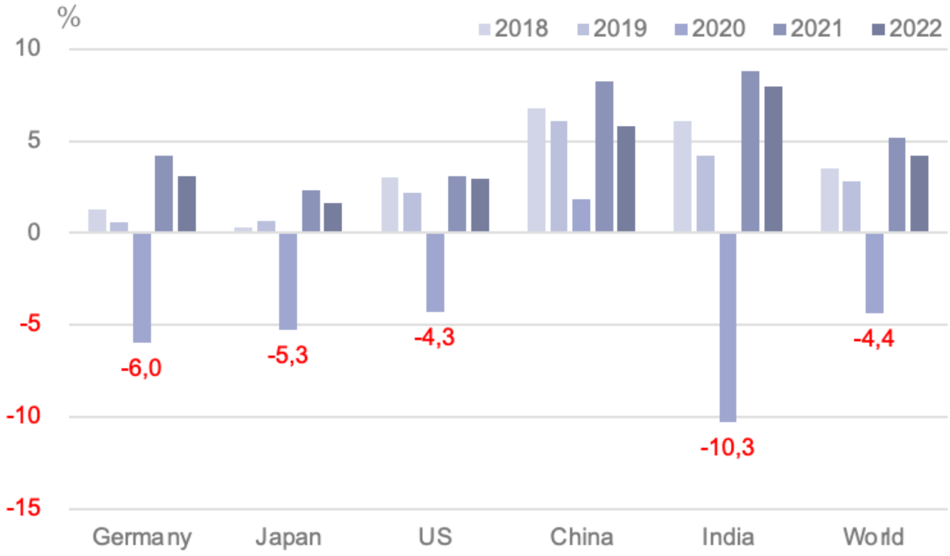


Figure 1 GDP growth rate of major economies
Source: IMF, World Economic Outlook Database, October 2020

The world's oil demand shrunk significantly and saw a historically high over supplied oil market which led to a negative crude oil price. But after that, production cut of the OPEC Plus has quickly rebalanced the market.

This chapter gives a brief overview of how the pandemic affected people`s life, work and industries in Japan and Germany.

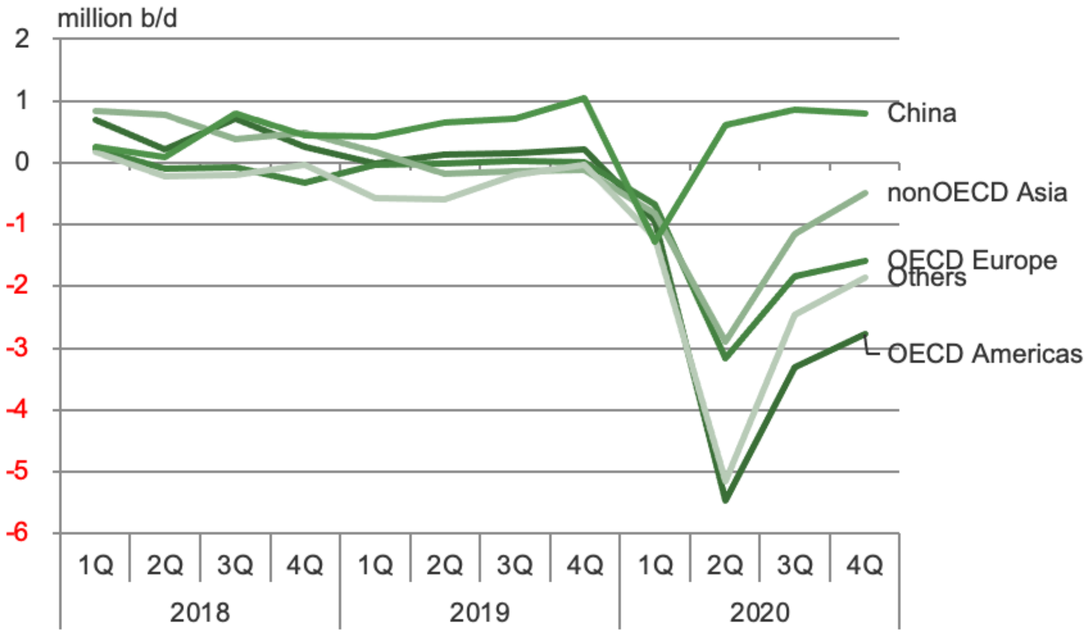


Figure 2 Trajectory of change of oil demand in major regions
Source: IEA, Oil market report

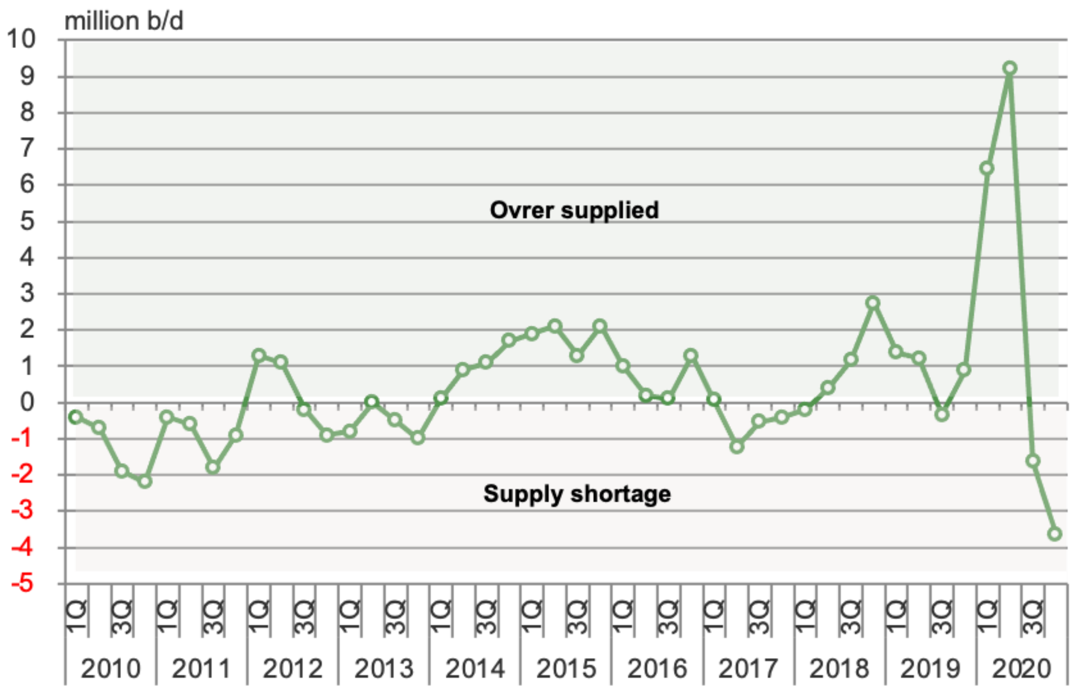


Figure 3 Trajectory of net crude oil balance
Source: IEA, Oil market report

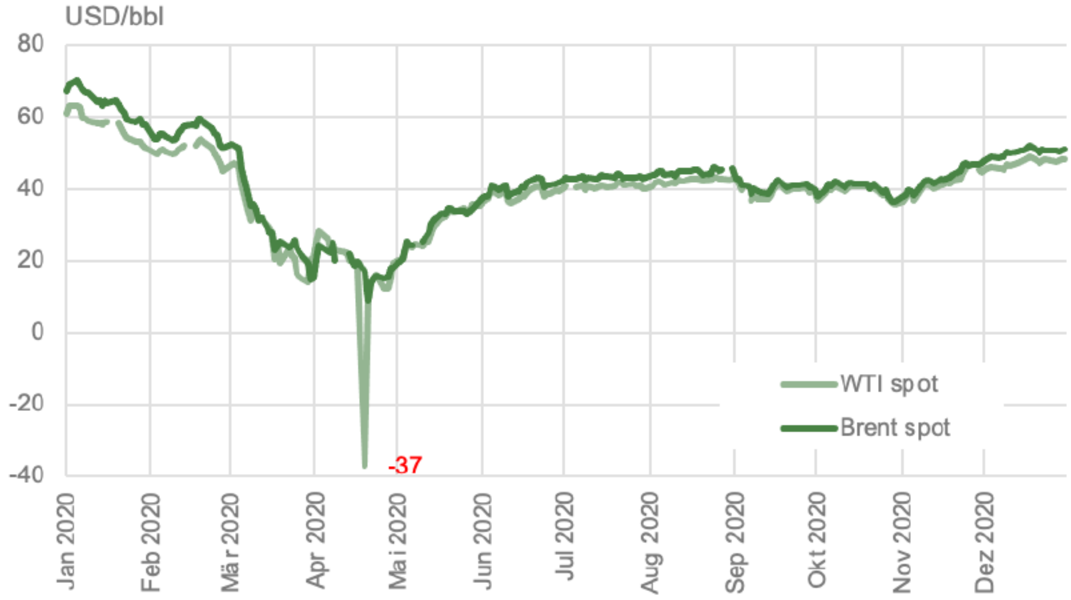


Figure 4 Trajectory of Brent and WTI spot crude oil price
Source: EIA, US Department of Energy

2.1 Japan

Covid-19 put various influences on Japanese society and economy. In Japan, a state of emergency was declared through the steps shown in the table below. The state of emergency was not a compulsory measure with penalties, but a request to voluntarily reduce the chances of contact between people to 20-30% of the normal level. In this respect, it is different from the so-called "lock-down" taken in Europe.

Table 1 History of the declaration of the state of emergency

Date of issue	Period until	Subjected region
7 April 2020	6 May 2020	7 prefectures including Tokyo
16 April 2020	6 May 2020	Expanded to all regions
4 May 2020	31 May 2020	All regions
14 may 2020	31 May 2020	Reduced to 8 prefectures including Tokyo
21 May 2020	31 May 2020	Reduced to 5 prefectures including Tokyo
25 May 2020	25 May 2020	End of the declaration

Source: Cabinet secretariat, the Government of Japan
(https://corona.go.jp/news/news_20200421_70.html)

Although it was lax restriction compare to that in European nations, we saw a significant depression of economy particularly in a second quarter of 2020 which we didn't experienced even during a financial crisis in 2008 and 2009.

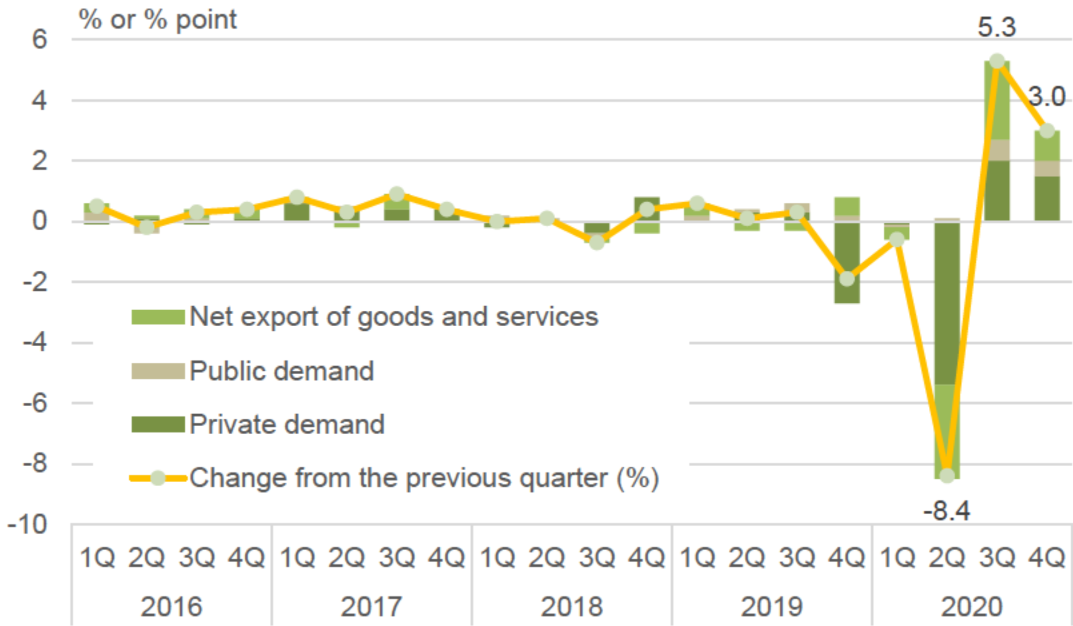


Figure 5 Quarterly GDP (seasonally adjusted) change in Japan
Source: Cabinet office, Quarterly GDP report

Change of life style

It can be said that the decrease in the amount of person trips is the biggest change in a life style. With government publicity to avoid the Three Cs[3], people are refraining from going out from home to reduce the risk of infection. Leisure and travel outings decreased the most, and restaurants, gyms, and other non-necessary outings were avoided as much as possible. After the end of the state of emergency

[3] Three Cs stands for closed spaces, crowded places, and close-contact settings.

on 25 May 2020, the number of people going out gradually increased, but even recently, it is still lower than usual[4].

Although it is inevitable to purchase daily necessities such as food, the frequency was reduced and visits to large shopping mall, which are likely to be crowded, were avoided. On the contrary, purchase opportunities at small stores near home have not decreased so much.

It has been reported that there is a tendency to prefer individual transport mode, that is, private cars, bicycles, and walking, to public transportation. However, since the amount of transportation itself is decreasing, the replacement rate of public transportation by individual transport mode may not be large.

In terms of consumption, it is characterized by a large increase in the use of online services. Instead of going to stores or restaurants, people have more opportunities to use online shopping and delivery services. In addition to entertainment or learning, daily communication is becoming more common online.

Changes can also be seen in the place of residence. Prior to Covid-19 pandemic, the influx of population into Tokyo exceeded the outflow. However, the number of out-migrants from Tokyo has been excessive for four consecutive months from July to October 2020. In the background, it seems that the number of people affected by Covid-19 is the highest in Tokyo and that the convenience of remote communication is widely recognized. Willingness for moving is especially high among the younger generation.

Change of work style

Remote work has become more popular in order to avoid contact with people. Overseas business trips have almost disappeared, and domestic business trips have

[4] Population at major train stations in Tokyo on working day in December is still 10% to 60% less than before Covid-19. (Agoop, 5 December 2020)

also decreased significantly. According to a government survey conducted from the end of May to the beginning of June 2020, the percentage of people who used remote work was 34.6%. The use of remote work was high at nearly 50% in education, finance, and wholesale sectors, while it was low at less than 20% in medical care, agriculture, forestry and fisheries, and retail sectors. By region, the remote work utilization rate was high in metropolitan areas including Tokyo. The use of remote work brings about a significant reduction in commuting time. Due to its convenience, many people who have experienced remote work want to continue this, especially in the Tokyo area.

When commuting, there is a growing willingness of avoiding public transportation, which is expected to be crowded. However, in many cases, it is thought that the actual change of commuting mode will be limited, because, for instance, an average commuting time in Tokyo metropolitan area is approximately 45 minutes by public transportation or car which is impossible to switch to commute by bicycle or on foot and because car parking charge is very expensive in business area.

Change of Industry

Production has fallen in many industries due to lower personal consumption and lower economic activity. The Indices of Industrial Production (IIP) has declined sharply in April and May 2020, when the year-on-year declining rate reached to almost -10 percent. By industry, the decline in automobiles and steel / non-ferrous metals was large. Production has picked up after June 2020 and has continued to recover.

The industrial sector generally has a long investment cycle, and the structure itself cannot change significantly in the period of less than one year from March 2020, when the influence of Covid-19 became clear, to the present.

Meanwhile, Covid-19 poses new risks to business continuity, such as disruption of domestic and overseas supply chains and shortage of personnel due to infection. Companies are seeking to strengthen their business continuity plan (BCP) by diversifying and domesticizing their supply chains and strengthening logistics and inventory management using digital technology.

In Japan, gasoline and jet fuel are the most affected energy after Covid-19. Damage of other energies, i.e. diesel oil, naphtha for feed stock, natural gas, and electricity are not so significant.

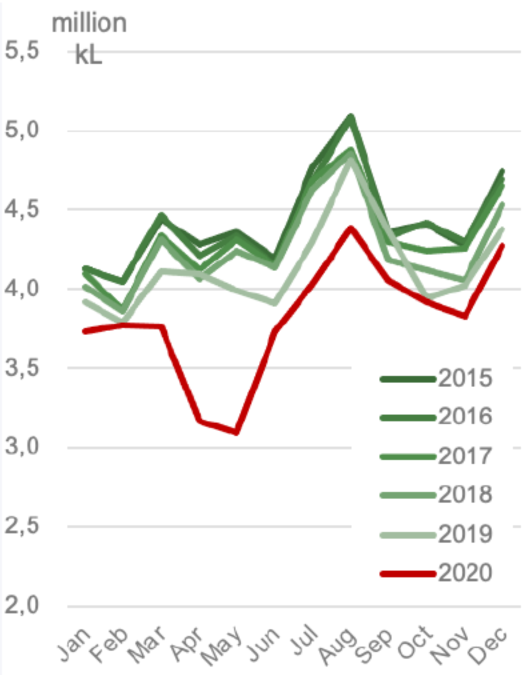
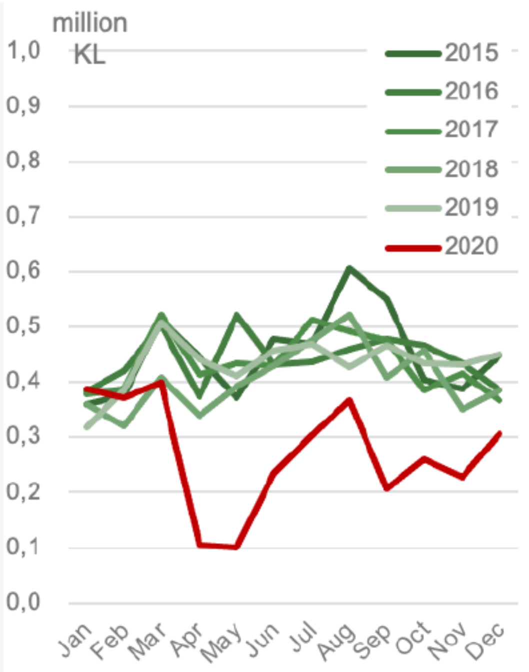


Figure 6 Trajectory of gasoline demand in Japan

Source: IEEJ, Data bank



Trajectory of jet fuel demand in Japan 1

Source: IEEJ, Data bank

2.2 Germany

Before the Corona pandemic it was expected that Germany will miss its 2020 CO_2 emission reduction target of 40% compared to 1990. Especially due to the Corona pandemic, however, it exceeded the target and achieved a reduction of 42.3%.[5] One of the main reasons cited is the drop in energy consumption in the transport and industry sector [6].

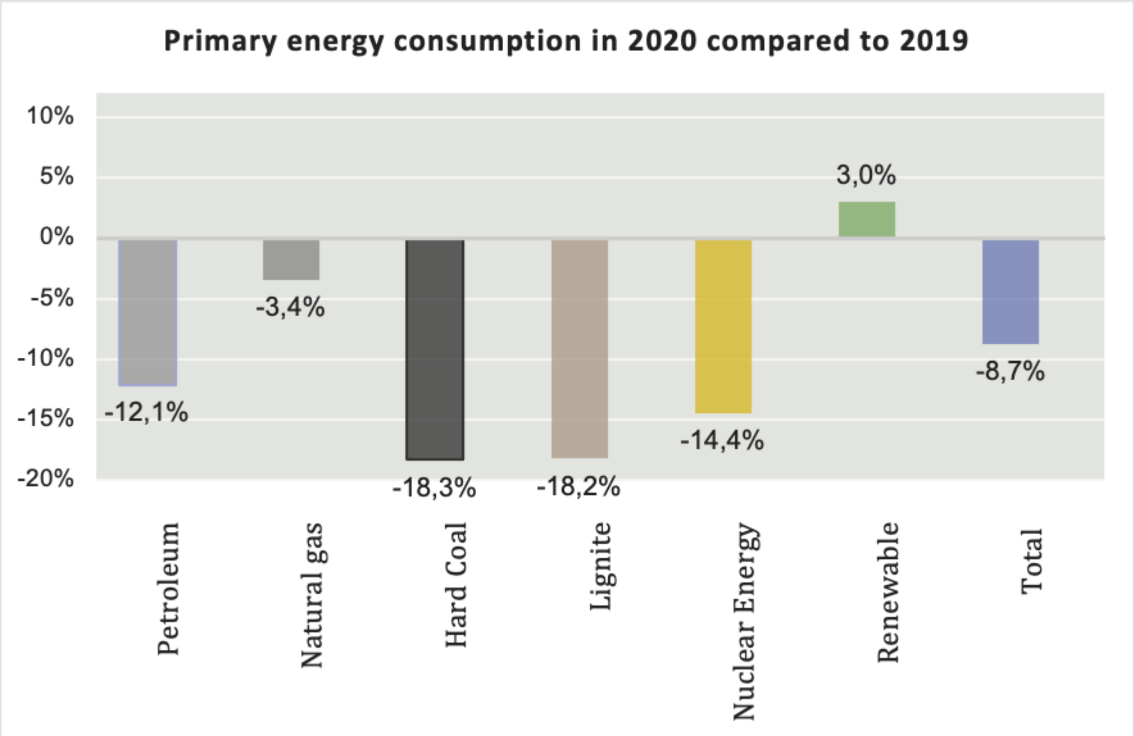


Figure 7 Primary energy consumption in 2020 compared to 2019

Source: AG Energiebilanzen (2020). Energieverbrauch sinkt auf historisches Tief Deutliche Auswirkungen der Corona-Pandemie / Anteil fossiler Energien sinkt. AG Energiebilanzen Pressedienst.

Figure 7 shows that total primary energy consumption in Germany fell by 8.7 percent in 2020 compared with the previous year, reaching an all-time low of 11,691 petajoules (PJ) or 398.8 million metric tons of hard coal equivalent (mtce)[7]. Interestingly natural gas was hit less in comparison to coal, nuclear and oil and renewable energy even increased during the pandemic.

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[5] Agora Energiewende, 2021. Die Energiewende im Corona-Jahr: Stand der Dinge 2020. Rückblick auf die wesentlichen Entwicklungen sowie Ausblick auf 2021.

[6] Emissions were reduced by 80 million tons of CO_2 to 722 million t. Without Corona it would have been only 25 million t (37,8%).

[7] https://www.ag-energiebilanzen.de/

But looking to the future, the Agora study warns that more GHG emissions could be expected in all sectors again as soon as the economy catches up [8]. This chapter describes in more detail the changes in industry, life and working styles that lie behind these numbers.

In Germany, profound measures were taken to slow down the spread of infections[9][10][11]. In spring 2020, schools, universities, most shops, restaurants and catering, but also service businesses in the field of personal care were closed, gatherings of more than two people were prohibited, and major events were banned. People were asked to follow hygiene rules, and to refrain from private travel and visits, accompanied by travel warnings and quarantine obligations for returnees. In April/May, some of the measures were loosened up. Towards autumn, however, the measures picked up again. Finally, there was another partial lockdown in November, which was further tightened during the winter months. Throughout the year, the pandemic thus changed people's lives significantly.

Changes in Industry and other sectors

„After several quarters with shrinking production in the manufacturing sector, the COVID-19 crisis has hit the German economy with unprecedented force. The simultaneity of multiple supply and demand shocks is likely to be unique compared to previous economic crisis“[12]. The quote summarizes how the overall economic

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[8] https://www.br.de/nachrichten/wissen/klimaziele-fuer-2020-in-deutschland-doch-noch-erreicht,SLDZF1G

[9] https://www.handelsblatt.com/politik/deutschland/covid-19-in-deutschland-coronavirus-so-hat-sich-die-lungenkrankheit-in-deutschland-entwickelt/25584942.html?ticket=ST-2066035-yivDatPvWugjA5zjhBnn-ap4

[10] https://www.deutschland.de/de/news/bundesregierung-und-corona-krise

[11] https://www.bundesregierung.de/breg-de/themen/coronavirus/bund-laender-corona-1744306

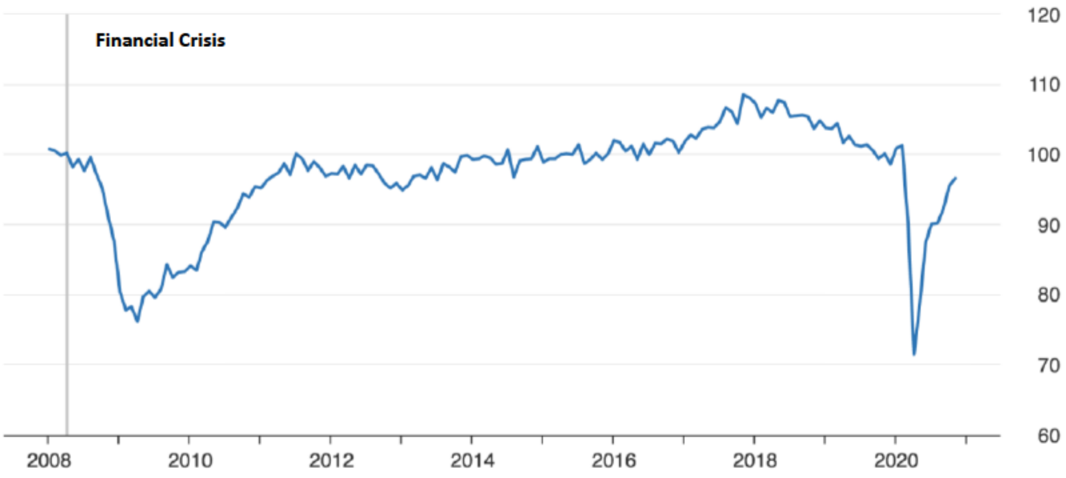
[12] See IW; The German Economic Institute (IW) sees its research as an „..advocate of a liberal economic and social order“ (Home page) and working closely with German Industry. https://www.iwkoeln.de/en/studies/external-studies/beitrag/hubertus-bardt-michael-groemling-germanys-economic-response-to-the-coronavirus-crisis.html

impacts of the Corona 19 crisis are perceived by most economists in Germany. Germany is particularly affected by the global pandemic because it is intensively integrated into global value chains. Domestic industry sales fell by 19.2 per cent, foreign sales by 28.2 per cent. The *automotive sector, machinery and plant engineering industries, aviation industry and the touristic sector* have been hit the most (The National Law Review, February 2, 2021) [13] The automotive sector suffers due to a collapse in global demand for new cars. Production went dramatically down by 53.6 percent in May compared to the same month last year.

While the health sector or parts of trade continue to operate more or less fully, the travel industry has almost come to a standstill along the entire value chain with 88% travel and tour operators in short work as well as 71% of hotels.[14] *Lufthansa* is severely affected by the pandemic and had to accept a rescue deal of €9 bn from the government to save it from a collapse. [15]

Many industrial enterprises are massively affected by disrupted supply chains and other impairments on the supply and demand side. Sectors where the risk of contagion is lower or where decentralized working is possible (home office) tend to be less affected.

[13] https://www.natlawreview.com/article/reflections-covid-19-views-germany
[14] https://www.natlawreview.com/article/reflections-covid-19-views-germany
[15] https://www.bbc.com/news/business-52801131



© Statistisches Bundesamt (Destatis), 2021

Figure 8 Production index in the manufacturing sector

As a result, during the Corona crisis, more companies put their employees on short-time work than ever before. According to estimates based on the results of the ifo Business Survey, the number of employees on short-time work in Germany amounted to 7.3 million in May 2020 (22% of all employees subject to social security contributions). In June, the number decreased slightly to 6.7 million. By comparison: at the height of the financial crisis, the peak of short-time work in May 2009, with just under 1.5 million employees, was only one fifth of the level estimated for May 2020. In the current crisis - unlike in 2009 - service sectors are also affected, and the period over which workers are supported with short-time allowances is longer than in previous crises [16] [17]. About 80% of metal producers are still on *short work*. On average the number of short work is decreasing, but the problem of underemployment continues and public support scheme (about 60-80% of salary) has been extended until December 2021.

[16] https://www.ifo.de/themen/coronavirus ; https://www.ifo.de/node/57436

[17] https://www.bmwi.de/Redaktion/DE/Pressemitteilungen/Wirtschaftliche-Lage/2020/20201014-die-wirtschaftliche-lage-in-deutschland-im-oktober-2020.html

29.000 additional possible *corporate insolvencies* have been estimated up to now, but fortunately have been mitigated for months by changes in the insolvence law. But what about future perspectives? (ibid).

With that in mind it is not surprising that short run *consumer spending* fell significantly, because of concerns about possible job losses. Though it is expected that consumption will be a main driver for recovery[18] it is not clear whether this will be connected with energy saving shifts of consumption patterns concerning e.g. on line shopping, mobility patterns, tourism.

To sum up the economic effects: „The coronavirus pandemic has caused an unprecedented global economic bust. At the same time, it will likely accelerate structural changes, which in turn are driven by digitalization, the energy revolution, decarbonisation and demographic changes“ (Intereconomics, 2021, ibid). Thus, the end of the corona pandemic in terms of illnesses and deaths - however depressingly long this end may lie ahead of us - is by no means the end of the possible far-reaching economic, social and political consequences of the pandemic. Thus the key question remains what these socioeconomic impacts imply for the energy transition, for fostering a decarbonisation strategy and for an integrated crisis management policy.

Is it possible to step forward to sustainable structural change and "better growth" which decouples economic development by innovations and green investments from GHG-emissions? Unfortunately, traditional macroeconomic quantitative analysis and projections are not very powerful to answer this question. On the one hand, there is talk of a double external shock (see above) on the economy and, as a result, massive *quantitative* growth losses. On the other hand, the hope is

[18] https://www.bundesbank.de/en/tasks/topics/coronavirus-pandemic-continuing-to-shape-german-economy-853776

expressed that with economic stimulus programs, it might be possible to create V-shaped, quick and high new *quantitative* growth impulses, to catch up to the old growth path again. *But what if the old growth path has not been sustainable at all?*

Change of life style

Around 40% of households suffered income and other financial losses due to the Corona pandemic and related measures[19], and thus became generally more cautious in their planned spending. Concerns about contagion, closed shops and entry regulations, strengthened the use of online trade which increased its sales by 23 % in August alone compared to the same month a year before (Destatis, 2020). Food and meal delivery services also experienced a boom. These trends not only led to a noticeable increase in delivery traffic in cities[20][21]. German households also produced significantly more waste than in previous years. The amount of plastic, other light packaging and glass collected rose by around 6% in 2020 (BDE 2020)[22]. On the other side, life and consumption shifted from the city centres to the city districts and neighbourhoods. Due to the use of home offices, people were increasingly shopping in the small shops on their doorstep and made greater use of the bicycle or walking instead of travelling by car or bus. Suburban locations that have so far not been optimally connected to the city centre suddenly gained in attractiveness (PwC 2020[23]).

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[19] https://www.bundesbank.de/en/publications/research/research-brief/2020-35-covid-19-pandemic-consumption-849870

[20] https://www.tagesschau.de/wirtschaft/lieferdienste-onlinehandel-corona-boom-101.html

[21] https://www.firmenauto.de/lieferdienste-im-staedten-wege-aus-dem-verkehrskollaps-10153014.html; https://merkurist.de/frankfurt/neues-system-stockender-verkehr-durch-lieferservice-forscher-suchen-loesung_Fd4

[22] German Association of the Waste Management, Water and Raw Materials Industry (2020)

[23] PWC, 2020.

Although everyday mobility is reduced overall [24], the car appears to be the 'winner among the means of transport in the Corona crisis', to a lesser extent also the bicycle. Among the 'biggest losers' are all public transport modes and car sharing, which trigger feelings of insecurity among users during the pandemic[25].

Clear changes also occurred in travel habits, especially when comes to vacation travel. Germans are considered to be the world's travel champions. However, during the Corona pandemic, the popular, but ecologically questionable long-distance travel [26] declined seriously [27]. Only about one third of German holidaymakers who would have been interested in a cruise in principle were still considering a cruise (Centouris 2020) [28]. Passenger air traffic came to a virtual standstill at times[29]. By contrast, Germany as a popular and low-emission holiday destination increased its share to over 50%. However, holiday destinations in Europe that can be reached by car have so far remained attractive if no travel warning was issued. But air travel at German airports collapsed dramatically (see Fig. 9).

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24 https://www.infas.de/neuigkeit/mobilitaet-und-corona-wie-veraendert-sich-der-alltagsverkehr/

25 https://verkehrsforschung.dlr.de/de/news/dlr-befragung-wie-veraendert-corona-unsere-mobilitaet

26 https://www.wwf.de/fileadmin/fm-wwf/Publikationen-PDF/Der_touristische_Klima-Fussabdruck.pdf

27 https://bzt.bayern/wp-content/uploads/2020/07/Reisen-in-Zeiten-von-Corona-BZT_Studie_Juli_2020_PDF.pdf

28 https://www.centouris.de/aktuelles/news/news-detail/wie-das-coronavirus-das-reiseverhalten-der-deutschen-veraendert/

29 https://de.statista.com/statistik/studie/id/72253/dokument/auswirkungen-des-coronavirus-auf-die-luftfahrt/

Figure 9 Air passengers at German airports
Source: Destatis (2021)

The requirement to stay at home increased the importance of communication in private life: phone calls, entertainment media, video conferencing, cloud services and streaming offers for event broadcasts (cultural performances, church services, etc.). Data traffic increased by leaps and bounds. Telekom recorded a 76% increase in fixed network communication in March 2020, streaming services and game clouding increased by 30% in this period[30]. More cooking, streaming and being most of the time in the home office with a permanent use of computers requires energy. Following a survey by Verifox (2020), the Corona pandemic has increased electricity consumption in many German households, especially among younger consumer groups. They estimate up to 150 euros more in electricity costs per year[31].

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[30] EY/WI, 2020; The DE-EIX internet exchange in Frankfurt is the largest in Germany and one of the most important worldwide.

[31] https://www.rnd.de/wirtschaft/stromkosten-steigen-durch-corona-bis-zu-150-euro-mehr-pro-haushalt-durch-homeoffice-zeit-BSOUAJQA45CX3N2DKXQM5AFATM.html

Change of work style

Before the Corona crisis, about 77% of German employees commuted daily to work[32], taking up to 1.5 hours. Only a minority used home offices. But due to the lock-down, the figure rose significantly to 61%[33], the potential not being exhausted yet (see figure 3). However, the home office potential is very unevenly distributed both by industry, region and social conditions (Ifo 2020). The digital transformation was accelerated by the Corona pandemic in the majority of companies (55%), with large companies implementing the digital transformation more consistently than small ones. Digital tools for communication were introduced (23%) or intensified (36%) as a result of the pandemic.

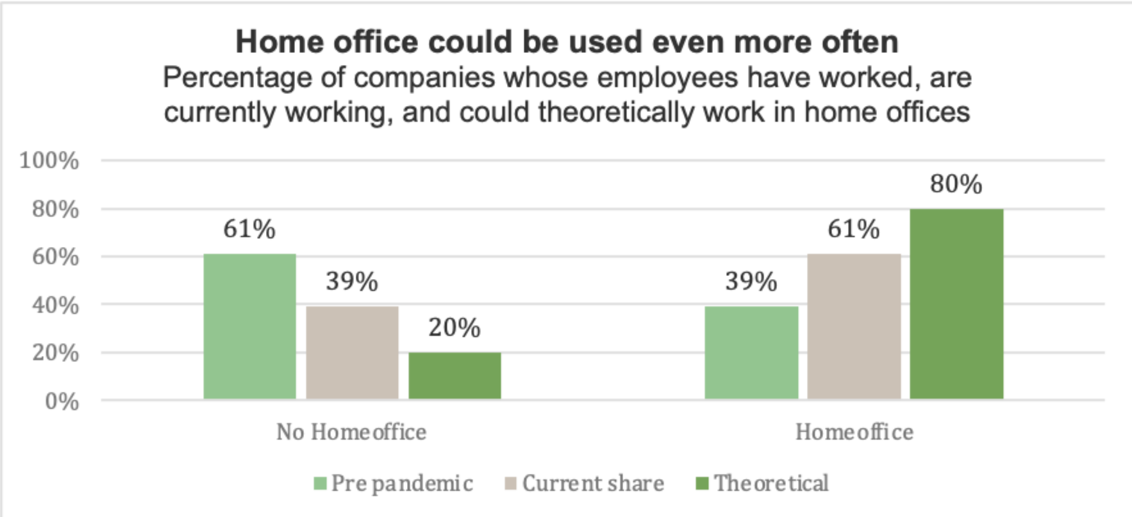

Figure 10 More companies can use home office

Video conferencing was part of the daily work routine for an increasing proportion of the workforce during the Corona pandemic. At the DE-CIX Internet node in Frankfurt, there was a 120% increase in videoconferencing in March. These

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[32] https://www.stepstone.de/Ueber-StepStone/wp-content/uploads/2018/04/StepStone_Mobilit%C3%A4tsreport_2018-1.pdf
[33] https://www.ifo.de/personalleiterbefragung/202008-q2

changes are likely to be permanent (see figure 4), as HR managers report that they intend to use more home offices (47%), hold more virtual conferences (64%) and fewer on-site meetings (59%) even after the Corona pandemic. In addition, 61% of companies say they plan fewer business trips in the future. In sum this could amount to a considerable substitution of physical (professional) traffic by data traffic (digitalization). Ernst and Young/Wuppertal Institute (2020) support this trend: *"Commuter traffic and business travel each account for 20% of all passenger traffic. […] it seems realistic that in the long term, 10% of all commuter traffic could be replaced by expanding the home office and 30% of all business trips by virtual meetings. Overall, this would lead to a reduction of 8% in passenger traffic"*[34]. Greenpeace (2020) estimates that CO_2 emissions from transport could be reduced by 5.4 million tonnes per year if 40% of employees worked permanently from home two days per week. This corresponds to 18% of all commuting emissions[35].

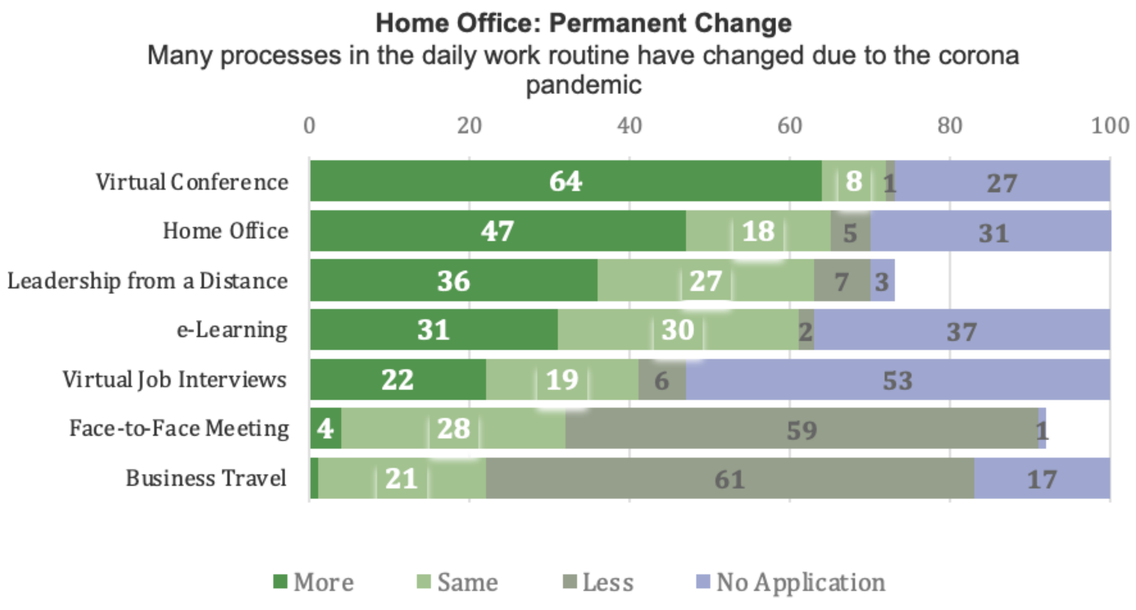

Figure 11 Home Office: Permanent Change

[34] Ernest & Young/Wuppertal Institute (2020): Interim report COVID-19 (Own translation)

[35] https://www.greenpeace.de/presse/presseerklaerungen/homeoffice-kann-ueber-5-millionen-tonnen-co2-sparen

3. Recovery programs and the energy transition

To overcome the massive societal and economic challenges caused by the covid-pandemic crisis, governments all over the world had to take short and medium term action and mobilized enormous financial resources. But the pandemic is hitting the world at a time where already a multitude of enormous societal, ecological and economic challenges exist that need to be solved: If the huge global public recovery programs to overcome the corona crisis do not take these other challenges into account, but continue with investments in outdated technologies which increase carbon intensity, this may exacerbate other problems, hinder the necessary innovation and reduce the economy´s competitiveness. This holds especially true for the climate crisis.

This chapter gives a brief overview on the stimulus packages in Japan and Germany and tries to identify in how far these measures address greater sustainability.

3.1 Japan

In Japan, two economic stimulus packages have been taken so far in response to covid-19. There are two main points of economic stimulus packages. The first is the strengthening of the medical system and the emergency protection of industries and individuals affected by Covid-19. Small and medium size enterprises (SMEs) were at a crossroads of business operation, and individuals suffered from declining income and unemployment. It is no wonder that the government puts these protections first. The second is support aimed at economic recovery and future growth. From this perspective, support will be provided that will contribute to strengthening the foundation for growth as well as economic recovery, such as strengthening the supply chain and expanding digital infrastructure. Climate change countermeasures are also included in this respect. However, the only identifies support menu is solar PV installation for the manufacturing industry.

Table 2 Budget plan for Covid-19 stimulus package in Japan

	Total size		of which, Fiscal expenses	
	Amount	Share to GDP	Amount	Share to GDP
The 1st additional budget (Apr. 2020)	JPY 117.1 trillion (EUR 976 million)	21%	JPY 48.4 trillion (EUR 403 million)	9%
The 2nd additional budget (Jun. 2020)	JPY 117.1 trillion (EUR 976 million)	21%	JPY 72.7 trillion (EUR 606 million)	13%
Total	JPY 233.9 trillion (EUR 1,949 million)	43%	JPY 120.8 trillion (EUR 1,007 million)	22%

Total size = fiscal expenses + contribution of (local government + government agency + bank, etc.)
Assume EUR 1 = JPY 120.   Assume nominal GDP in 2019 = JPY 549.5303 trillion.
Source: Cabinet office, Emergency Economic Measures to Cope with the Novel Coronavirus (COVID-19), 20 April 2020, etc.

In addition to it, the government announced the third stimulus package in December 2020. The package consists of three pillars: "Prevention measure against Covid-19 infection", "transformation of economic structure toward post-corona era", and "strengthening disaster resilience of the land." Of these, "Transformation of economic structure toward post-corona era" clearly states policy for the realization of carbon neutrality, which is different from the past two packages. This is because the government poses the challenge of carbon neutrality as a new growth strategy in response to Prime Minister Suga's declaration of carbon neutrality ambition in October 2020.

Table 3 Japan's budget for Covid-19 third stimulus package

	Total size		of which, Fiscal expenses	
	Amount	Share to GDP	Amount	Share to GDP
The 3rd package (Dec. 2020)	JPY 73.6 trillion (EUR 613 million)	13%	JPY 40 trillion (EUR 333 million)	7%

Assume EUR 1 = JPY 120. Assume nominal GDP in 2019 = JPY 549.5303 trillion.

Source: Cabinet office, Stimulus package for peace and hope to protect the citizen's health and life, 8 December 2020

Specifically, the following plan is shown in the package:

- Established a 2 trillion yen R & D support fund. The priority areas are;
  1) electrification of demand and decarbonisation of electricity,
  2) realization of a hydrogen society, and
  3) carbon capture utilization and storage (CCUS).
- Supports decarbonisation of automobiles, improve heat insulation of building, and expand use of distributed energy.
- Contributing the decarbonisation of the world.

3.2 Germany

In response to the Covid-19 crisis, the German government adopted two economic stimulus packages that were introduced in March and June 2020. The first measures ("Corona Aid Package") aimed at a short-term support: spending on healthcare & vaccine, short-term work, subsidies for small business owners & self-employers, as well as an expanded duration of unemployment & parental leave. The second package focused at a more long-term economic stimulus and is particularly important regarding its climate impacts as they comprise (besides many other aspects) subsidies and investment in green energy and digitalization.

Summarizing the first package, the Federal Ministry of Economic Affairs and Energy (BMWi) highlights the temporary reduction of VAT (from 19% to 16% / for the reduced rate 7% to 5%; July to December 2020), a child bonus for families and the strengthening of municipalities, as the federal government increased the support for the costs for housing for the needy, compensates half of the municipalities' trade tax losses and strengthens local public transport and the health sector. Furthermore, electricity costs will be reduced: The EEG levy is to be reduced from 2021 onwards through subsidies from the federal budget. A bridging assistance programme will support small and medium-sized enterprises.

As part of the second recovery program the so-called "future package" has been decided: Around 50 billion euros (about 38%) will flow into future technology areas such as the hydrogen economy, quantum technologies and artificial intelligence (see below).

Table 4 German Budget plan for Covid-19 stimulus package

	Total size	
	Amount	Share to GDP
Rescue Package March 2020	EUR 156 billion (JPY 18700 trillion)	4,9%
Recovery Programm June 2020	EUR 130 billion (JPY 15600 trillion)	4%
Loans, guarantees and sureties	EUR 757 billion (JPY 90840 trillion)	24 %

Assume EUR 1 = JPY 120. Assume nominal GDP in 2019 = EUR 3.44 trillion
Source: https://www.bundesregierung.de/breg-de/aktuelles/konjunkturpaket-geschnuert-1757558
Ergebnis Koalitionsausschuss 3. Juni 2020 ;
https://www.statista.com/statistics/295444/germany-gross-domestic-product/

In addition, the German government is expanding the access to public guarantees and the volume of available guarantees for firms through the newly created WSF (economic stabilization fund) and the KfW (development bank). Both together enable a volume of at least 757 billions which sums up 24 percent of GDP. Although the German council of economic experts emphasized that a great share of measures budget have not been used so far.

Climate mitigation measures and sustainability

In the future package, the German recovery program (as of June 2020) does indeed list a number of measures that address sustainable structural change and climate change mitigation, and tries to combine economic and ecological targets. The measures mostly refer to the field of sustainable mobility and the energy transition, while other issues like digitalization and education are supported, yet without further specifications in terms of climate mitigation or sustainability goals. Table 3.4. presents a more detailed list of the activities.

Table 5 Sustainable measures within the second German stimulus package

Field	Measures
Promote investment by businesses and local authorities	▪ **Financial support for local public transport**: Provision of a one-off extra government subsidy of €2.5 billion for public transport in 2020.
Sustainable mobility	▪ Doubled innovation premium (€ 6,000) for purchase of electric vehicle (until 31 December 2021) ▪ Additional invest of in the expansion of state-of-the-art, safe **charging infrastructure** and in R&D funding for **electric mobility** and **battery cell production** (€2.5 billion) ▪ Bonus programme in 2020 and 2021 of €1 billion in funding to promote **forward-looking investment** by manufacturers and suppliers in the automotive industry. ▪ From 2021 onwards: Motor vehicle tax rates, based on carbon emissions (clean cars subject to lower rates than high-emission cars). ▪ Temporary **vehicle fleet replacement programme** to promote electric mobility, aiming at vehicles used by social services in urban traffic and commercial

	vehicles used by small and medium-sized firms. ▪ Investment in a programme to **modernize** the country's fleets **of buses and heavy goods vehicles** to promote the use of vehicles that run on power other than fossil fuels. Temporary increase in funding for electric buses and the necessary charging infrastructure in 2020 and 2021. ▪ Call for an **EU-wide HGV replacement programme** that will provide grants for the replacement of older, higher-emission vehicles (i.e. compliance with Euro 3 to Euro 5 emissions standards) with new vehicles that comply with Euro VI standards. ▪ Provision of €5 billion in additional equity to the railway company **Deutsche Bahn**, so despite revenue losses due to the Covid-19 pandemic, key investments in the modernisation, expansion and electrification of rail networks and the overall railway system will be possible. ▪
Energy transition	▪ Ambitious investment package to promote **hydrogen technology** to lay the groundwork for new export technologies and make headway towards carbon neutrality in HGV traffic. ▪ Grant to reduce the **surcharge levied on electricity consumers** to 6.5 cents/kWh in 2021 and to 6.0 cents/kWh in 2022. ▪ The cap on **solar power** expansion will be revoked and the target for expanding **offshore wind power** will be raised. ▪ Funding for the **CO_2 building renovation programme** will be raised to €2.5 billion in 2020 and 2021 (an increase of €1 billion).

https://www.bundesfinanzministerium.de/Content/EN/Standardartikel/Topics/Public-Finances/Articles/2020-06-04-fiscal-package.html# (2020/12/07)

Finally, the German Recovery Program must be seen in the context of European Programs. The EU's Recovery and Resilience Facility (RRF) will provide member states with up to €672.5bn in funding intended to support the economic recovery from the COVID-19 crisis. In order to receive these funds, every member state must ensure that at least 37% of spending in its national recovery plan is aligned with the green transition, with the remainder of the funding not doing significant harm to the transition to climate neutrality [36].

[36] https://experience.arcgis.com/experience/f2700c9b597a4aababa4c80e732c6c5c?views=view_17; https://greenrecoverytracker.org/

4. Impacts on policy making and policy style

4.1 Japan

The impact of Covid-19 and its subsequent changes on Japan's policymaking can be broadly expressed by three keywords: "strengthening the supply chain", "digitalization," and "carbon neutrality".

The first "strengthening the supply chain" is aimed at strengthening the supply chain because the outbreak of Covid-19 disrupted the supply of resources, including not only materials and equipment but also human. For example, in the automobile industry, the domestic production line had to be stopped due to the delayed supply of some parts from overseas such as China. Although each company has taken measures such as diversifying parts suppliers, the disruption of supply chain at the same time throughout the world was beyond of their imagining. The situation was exacerbated by the tendency to consolidate manufacturing bases and not hold a large inventory from the economic efficiency point of view. Another example in medical supplies, demand has risen sharply, and general-purpose products have run out due to their reliance on China for much of their supply. Masks were sold at unusually high prices in the e-commerce market, and the government began to regulate it. From these cases, the government emphasizes the need to identify risks in the supply chain and manage crises according to the characteristics of supplies. For energy supply with physical restrictions on domestic production, the government emphasizes importance to diversify suppliers and secure international trade.

The second "digitalization" aims to strengthen digital infrastructure as a new social infrastructure, a foundation for future growth, or a tool for strengthening the supply chain. Although the importance of digital technology has been recognized since before Covid-19, and efforts have been made to expand its use, its implementation in society has been gradual. However, remote communication has become unavoidable and has become common rapidly, as contact between people has been withheld due to the need to control infection by Covid-19. Various exchanges, leisure and business habits that were traditionally face-to-face have been replaced by remote communication. Such a rapid shift would not have been possible without the coercion of Covid-19. The government sees this as an opportunity and intends to strongly promote digitalization. In the background, there is a recognition that the generalization of remote communication will accelerate new globalization that does not depend on the physical movement of people[37]. This decision is also supported by the fact that Japan's industrial structure is changing from traditional trade-led to investment-led. As the center of gravity of pursuing added value through international exchange is expected to shift to the digital field, Japan is aiming to increase its competitiveness in this arena.

The third "carbon neutrality" is rapidly gaining interest after the announcement by Prime Minister Suga in October 2020. Aiming for economic recovery from Covid-19 and long-term economic growth, the government is trying to position decarbonisation as a source of growth for the next generation, along with digitization. Through the development and investment of various innovative technologies and services that contribute to decarbonisation, the government will seek not only to build an environmentally sustainable society, but also enhance the competitiveness of the Japanese economy. The future picture assumes carbon neutrality in 2050 and the debates for designing the path to realize it have just begun. The hurdles for achieving the goal are very high, and the process of transforming the industrial structure and energy supply and demand structure may

[37] So called “third unbundling” in “The Great Convergence” (Richard Baldwin, 2016)

cause pain to the industry and each individual citizen. As such, without the shock of Covid-19, the government might not have been able to make this big decision in a short period of time. If so, the declaration of Carbon Neutrality in 2050 is perhaps the biggest change Covid-19 has made in the energy and climate sector in Japan.

Lastly, it should be pointed out that these three essential points are not independent of each other, but should be structured so that they are interlocked and enhanced with each other. For example, digital technology is an effective tool for strengthening the supply chain, such as inventory management and distribution optimization. It can also be applied to the optimization of energy supply and demand, such as the integration of intermittent renewable energy resources into the power grid. Alternatively, increasing renewable energy, which is essential for achieving carbon neutrality, improve the resilience of energy supply system and, as a result, contributes to the strengthening of the supply chain of various goods. In this way, the three elements can complement each other, and it can be expected that the anticipated benefit will be maximized by an integrated approach.

4.2 Germany

In addition to the severe impacts on production and consumption, there is a general consensus, that the Corona pandemic will have important *impacts on public finance and the distribution of income and wealth.* This includes policy changes as well: The *balance of stabilisation policy and (ecological) industrial policy* will probably change in Germany in connection with conceptualising and financing the recovery programs. The public acceptance that ecological industrial policy should aim to change the level and structure of production and investments in a more sustainable direction and by a „just transition“ also at the regional level, has increased. Thus Covid crisis induced structural change will happen anyway. But it remains to be seen how inclusive possible new growth pattern will be[38] and how far state interventions can guide and incentivize them in the direction of decarbonisation. In this respect financial policy is key in a German and European context.

Debt policy in Germany: a paradigm shift at the horizon?

The focus in this chapter is the impact of the pandemic on German finance policy and the underlying change in policy style. From an outside view this focus might be strange. But for the debate on financing recovery and climate mitigation programs in Germany and Europe ("Green deal") it is very relevant.

Chapter three has shown that the dimension of the German recovery package is huge. This chapter aims to contextualise this impact on the style of policy making and financing in Germany.

Before analyzing possible changes of the style of policy making it is important to get an idea of the framework that has shaped Germany's fiscal policy over the past decades before the pandemic began. In 2009, after the financial crisis, the fiscal rules in Germany`s fiscal policy were changed from the so called "golden rule"[39] to the "debt brake", a balanced-budget rule that restricts the structural deficit of the federal government to a maximum of 0.35% of Gross Domestic Product (GDP).[40] The „golden rule" in contrast permitted the state to incentivize investments financed through deficit spending and credits[41] and were thus much less restrictive than the debt brake actually is.

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[38] See https://www.intereconomics.eu/contents/year/2021/number/1/article/covid-19-and-the-growth-potential.html

[39] The golden rule of financial policy states that an increase in public debt can be accepted to the extent that it is accompanied by an increase in net public wealth that is at least as large.

[40] Potrafke, N., Riem, M., & Schinke, C. (2016). Debt Brakes in the German States: Governments' Rhetoric and Actions. *German Economic Review*, *17*(2), 253–275. https://doi.org/10.1111/geer.12089

[41] Truger, A., Friedrich-Ebert-Stiftung, & Abteilung Wirtschafts- und Sozialpolitik. (2015). *Reform der EU-Finanzpolitik: die goldene Regel für öffentliche Investitionen.*

Within the last few years, there have been intensified debates in Germany about the extent to which the debt brake was responsible for an investment backlog. The debt brake was implemented only with a general escape clausal that permits the federal government to exceed debt limits in case of natural disasters and extreme situations like crisis. This holds true for COVID 19 crisis, which led to a new level of indebtedness to finance recovery packages and guarantees, discussed in chapter three. Also in the European comparison the size of investment made by the German government is huge: *"Within the European Union, the German direct fiscal impulse is by far the largest across all member states. Moreover, including other types of public support such as tax deferrals and state guarantees, the German figure rises to almost 40% of GDP, which is outstanding in international comparison."(Südekum & Hüther, 2020 p.11f).*

Such state intervention was not imaginable across influential political parties and most academic economists before. According to Hüther and Südekum (2020) since many years before the pandemic German fiscal policy was driven by the neoliberal concept of a reduced state involvement. Thus the consensus between leading parties on the introduction of the debt brake in 2009 reflected the paradigm of a "Slim State" („Schlanker Staat”) that has been politically and socially dominant since 1980s (Südekum & Hüther 2020, p.38f).

Therefore, to combat the possible disastrous economic impacts of the COVID-19 crisis and to justify the huge financial interventions, led to an intensive public discussion on how the German debt brake can be redesigned. Additionally, there is an ongoing discussion on how to deal with the *debt after the pandemic* and how to reduce the debt. This could further change the policy style by imposing higher income and wealth taxes on very rich people depending on the possibility, that a new coalition comes to power after the elections in autumn 2021. But an opposite policy outcome could be possible as well - a roll back to the past e.g. a stronger austerity policy.

The still dominant position in the government is that the recovery programs were only justified by general escape clausal. This implies that immediately after the pandemic German financial policy should step back to the „old normal“ of the debt brake. This might only be possible by reducing public expenditures or rising tax revenues.

Thus, a general debate on questions of deficit spending, the priorities of public finance and a possible rationale behind increasing public dept under certain conditions is going on.[42].

Oversavings and a possible paradigm shift

'Oversaving' is the macroeconomic divergence of savings and investments that emerge when both main sectors, private households and industry are generating surpluses relative to their equity (Hickel 2020)[-43]. This means – concerning the national finance balance – that these sectors are net creditors and the state (or foreign countries) are net debtors. In principle, this divergence can be productively closed by deficit spending of the state and thus inducing private investments. Instead, the German fiscal policy has sharpened this discrepancy in the past years through *additional savings* (budget surpluses) that were caused by restrictive fiscal policy: the debt brake.

Thus the argument concerning the policy style is as follows: Oversavings are reducing the scope for state induced private investments, hinder target driven

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[42] This is actually discussed by the rather conservative institute leaders of the IW: Michael Hüther & Jens Südekum. (2020). How to re-design German fiscal policy rules after the COVID19 pandemic. 04/2020.

[43] Hickel, R. (2020). Staatliche Kosten der Covid-19-Krise – Die Rechnung begleichen Corona-Solidarfonds, Staatsverschuldung und Vermögensabgabe. Arbeitsgruppe Alternative Wirtschaftspolitik. https://www.alternative-wirtschaftspolitik.de/de/article/10656381.staatliche-kosten-der-covid-19-krise-die-rechnung-begleichen-corona-solidarfonds-staatsverschuldung-und-verm%C3%B6gensabgabe.html

public industrial policies and thereby shrinking the potential of transformative dynamic forces, reducing opportunities for innovations, new („green") business fields and more sustainable growth patterns.

Thus, in the short run the Corona Crisis caused a strong shift in German fiscal policy. Due to the huge recovery packages the state used a large amount of public money to incentivize private investments e.g. fostering the market introduction of hydrogen and thereby interrupting the circle of oversavings.

Nevertheless, this macroeconomic justification of state deficit spending in favour of future („green") investments is criticized by those who see the increasing national debt in many countries as a problem of the stability of the financial system. However, Germany's national debt ratio before the Corona crisis was comparatively moderate 59,8% (2019) and is now expected to rise to around 73% (2021) as a result of the corona crisis.[44] But even this rising level of debt is now viewed by many economists as unproblematic as long as the interest rate for government bonds is low or even in the negative range: The interest expenditure of the German federal budget fell from a maximum of 40.2 billion (2008) to 11.9 billion (2019); it is estimated that due to *negative interest rates and the relatively high creditworthiness of Germany as a debtor,* by December 2020 the *interest income* for the federal government even totaled 7.1 billion Euros. [45]

In Germany as also in the EU (concerning the financial concept behind the Green Deal[46]), the perception of the role of the state has changed to more proactive policy interventions and „greener" industrial policies as well. This might have major implications for public incentive programs to foster the energy transition.

[44] iwd 2020, https://www.iwd.de/artikel/neuverschuldung-in-corona-krisa-unausweichlich-468294/

[45] https://www.reuters.com/article/germany-bonds-idUSL8N2IV2AM

[46] e.g. European Commission 2020 https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/actions-being-taken-eu_en

The favourable development of the interest rates for public bonds is one reason behind this change. Another and may be a long term new trend is a changing attitude of the broad public and also growing fractions of the industry towards more ambitious climate mitigation. This change was driven by a strong global youth movement (Fridays for Future) in 2019, by new scientific information, by decisions declaring climate emergency (e.g. EU parliament Nov 11, 2019)[47] and by analytical evidence that the macroeconomic net-effects of climate protection are beneficial for economic development and competitiveness of the German industry.

The policies of a „Great Transformation"

It is not only the perception of the economic role of the state and its fiscal policy which might change by the impact of the Corona-Crisis. Further more, it is likely that the many priorities of government tax revenues (see above) and especially of government spending policy, will also change. For example, it is conceivable that major changes will take place in favor of accelerated digitization of schools, to increase the resilience of the health system, to decide on interventions for the labor market in favor of more home offices and may be on new priorities in transport policy, e.g. in favor of cycling and walking, at the expense of the long-distance tourism and air travel. It can be taken for sure that politics has to react to social changes and behavioral shifts, which can be intensified or slowed down by the corona pandemic. It is also possible that much debated scientific impulses for a fundamental "Great Transformation" (WBGU 2011) will acquire new socio-political relevance. This also applies to questions of governance in energy and climate policy as well as broader citizen participation.

The report published by the WGBU (2011) outlined that in order to conduct a fundamental socio-ecological transformation, the German society has to leave the

[47] https://www.euractiv.com/section/climate-environment/news/european-parliament-declares-climate-emergency/

business as usual path as soon as possible. It thereby emphasized already in 2011 the importance of a more proactive state („gestaltender Staat") to enable and guide a socio-ecological transformation. Therefore it is important to analyze in detail the governance of transformation in the light of new challenges and social learning due to the Corona Pandemic. For example, energy system transformation and more ambitious decarbonisation strategies have gained importance in all Member States of the EU, which might require a change in multi level energy and climate mitigation governance. On the one hand local action, citizens participation and decentralized technologies will be more important especially when it comes to secure acceptance for structural economic change and deep transformation processes. On the other hand, a coordinated action at the EU level across countries will be essential for a successful EU-wide implementation of policies and measures. This could mean that EU-regulation and governance e.g. conducting energy and resource efficiency, supporting a circular economy and reducing the fleet consumption for sustainable car mobility will gain more importance.

In sum, on the one hand the list of *possible* deep and dramatic changes due to the Corona pandemic in Germany and Europe is growing the longer the pandemic lasts and the more it puts pressure on society, economics and politics. On the other hand, uncertainty about only short run changes or long run shifts is growing dramatically.

5. Preliminary comparisons

The aim of GJETC studies is to compare topics of mutual interest in both countries at first with a country specific perspective. This generates information on possible similarities and differences. An additional step can be to explain *the reasons and drivers* behind similar or different developments to generate more specific information for learning from each other. In this preliminary short study, only a very brief comparison of selected topics is possible. This comparison can be extended by conducting a more comprehensive study (see section 6.)

5.1. Different health background

As of January 21, 2021 there were 2,100,618 numbers of infections and 40,936 numbers of deaths in Germany. In Japan in contrast there have been 345,221 confirmed cases of infections and 4,743 numbers of deaths.[48] Accordingly the numbers of other countries in Asia (e.g. China, South Korea) were much lower than in the USA or in European Countries (e.g. Britain, France, Italy or Spain).[49] This striking discrepancy holds the more true if you relate the figures to the different numbers of the population.

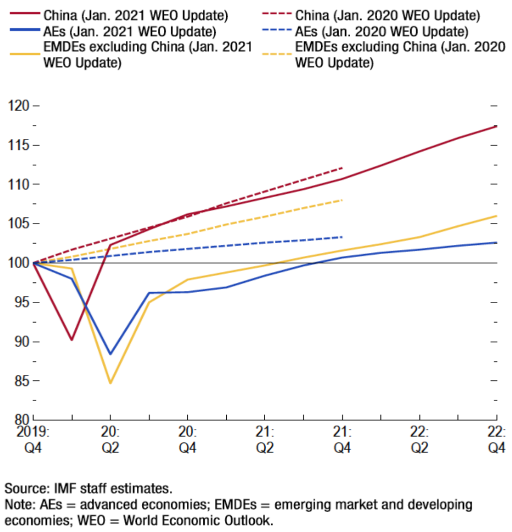
The anaylsis in this paper started in the light of these different health impacts of the COVID-19 crisis without aiming to explain possible reasons behind it. But it can be expected that the different country specific health impacts will have a significant influence on the economy, on the public perception of the pandemic, on the responses of politics and the policy style and especially on the duration, the concrete strategies and the impacts of the lockdown measures. For example, in Germany the fear of an exponential growth of infections, of a growing number of daily deaths and the impact of even more dangerous mutations of the virus have strongly influenced the duration and the severness of the lockdown. It would be interesting to compare if similar policy reactions happened in Japan and which economic and social effects were related to it.

[48] Compare https://www.nippon.com/en/japan-data/h00673/

[49] See the concrete figures in https://www.nippon.com/en/japan-data/h00673/

5.2 General economic context: Different recovery perspectives?

Does the global economic context cause different patterns of socioeconomic recovery in Germany and Japan? Up to now (January 2021) the impacts of the Corona pandemic on global economic developments were serious but differently spread all over the world. For the years after the pandemic unequal economic perspectives are expected as well according to global projections. For example, the latest Word Economic Outlook of the International Monetary Fund (IMF)[50] depicts the following different economic impacts of the pandemic on economic recovery for advanced economies and emerging markets/developing economies:



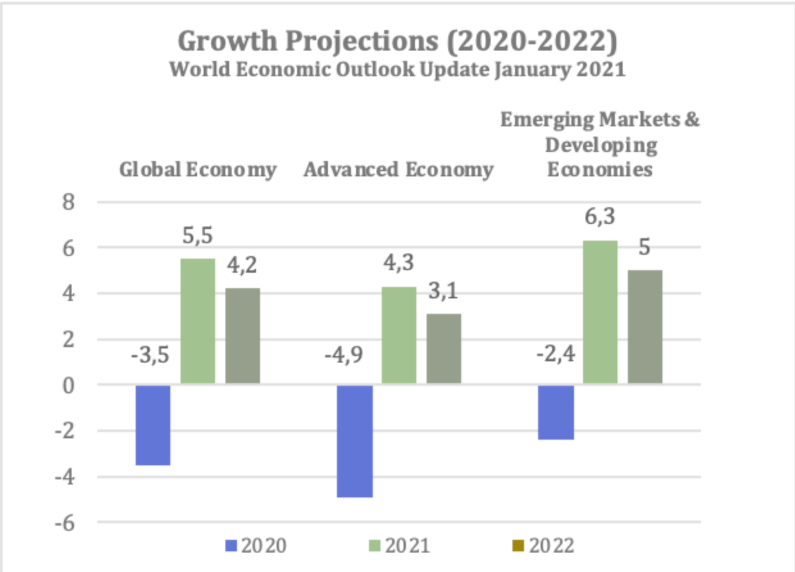


Figure 12 Divergent recoveries: WEO Forecast for Advanced Economies and Emerging Markets and Developing Economies (Index, 2019: Q4 =100)

Source: IMF https://www.imf.org/en/Publications/WEO/Issues/2021/01/26/2021-world-economic-outlook-update

[50] https://www.imf.org/en/Publications/WEO/Issues/2021/01/26/2021-world-economic-outlook-update

According to these projections e.g. China will recover much quicker than advanced economies. Will this be the case in other Asian countries, including Japan, as well?

The economic analysis by the OECD [51] (as of 12/2020) expects a *reduction in GDP* of 4.2% for the global economy in 2020. *Japan's* GDP is expected to decline 4.25% in 2020, with a slow increase of 2.25% in 2021 and 1.5% in 2022 if another stimulus program is launched. For *Germany*, the OECD is forecasting a slump in growth of minus 5.5% in 2020 and a slow recovery of 2.8% in 2021 and 3.3% in 2022.

In the consequence, CO_2- emissions and energy consumption in 2020 fell in both countries. As has been shown, in *Germany* CO_2 emissions were reduced by about 80 Million t of CO_2 (55 million t due to the pandemic). Energy consumption in Germany fell by 8.7 percent, reaching 11,691 petajoules[52]. In *Japan*, primary energy supply fell by 9.1 percent, reaching 18,275 petajoules[53]. Consequently, CO_2 emissions were reduced by about 10 percent as higher carbon content energy, i.e. oil and coal, experienced larger drop than natural gas[54].

If the vaccine delivery is not delayed and new outbreaks are contained a V-shaped recovery in German and Japan might be possible. But Japan and Germany are „no save heavens“ in a globalized world. It is not only a matter of justice but of economic rationality as well to support other countries, especially when they are poor, with sufficient vaccine facilities. But the activity gap on this challenge is still huge. Thus it might be a too optimistic estimation when the OECD states: "In many

[51] OECD (2020), OECD Economic Outlook, Volume 2020 Issue 2: Preliminary version, No. 108, OECD Publishing, Paris, https://doi.org/10.1787/39a88ab1-en

[52] https://www.ag-energiebilanzen.de/ (17.12.2020)

[53] IEEJ, Data bank

[54] A simple estimation by multiplying the emission intensity of imported crude oil, imported steam coal, and LNG.

countries, economic output will not have reached the level of 2019 even by the end of 2021."[55]

When it comes to more detailed analyses on *possible long lasting effects* in Japan and Germany the picture is very dispersed and uncertain. Although massive sector and industry-specific slumps are noted as a result of the Covid-19 crisis, their possible effects e.g. on structural change in the post-Covid period are not recorded in aggregated macroeconomic projections.

For example, the crisis has put a spotlight on *globalized supplier dependencies* and a lack of crisis resilience. What lessons learned were derived from this impact in Germany and Japan? Will both countries return to the "old" growth path and if so, will this meet the requirements of the future? For example, a new trend of regional reorientation and „...restructuring of supply and production processes along very stretched–out international value-chains „(ibid) might occur. Thus by new patterns of international division of labor the relation between national and externalized energy consumption and GHG-emissions might change.

Production in the automotive sector went dramatically down in both countries. But in Germany the automotive sector also suffers because the transformation to more sustainable transportation patterns (including e-Mobility) has started years before the Corona pandemic and was not taken seriously by German car makers; but the shift to E-cars is now changing rapidly. In Japan, social changes as well as climate action is demanding a structural shift in the automobile industry, which is said to be "once in 100 years". Covid-19 is irreversibly changing communication and living styles. This also poses difficulties in operating public transport, which is more energy efficient than automobiles. Both Japan and Germany, which have been

[55] http://www.oecd.org/wirtschaftsausblick/dezember-2020?utm_source=berlin-newsletter&utm_medium=email&utm_campaign=ecooutlookdec2020&utm_content=de&utm_term=ber

world leaders in the automobile industry, are under pressure to seek out sustainable mobility services.

5.3 Comparable impacts on specific sectors and life style

Some observed specific effects in Japan and Germany are similar: the traffic volume decreased, public transport and especially air travel were reduced strongly, while the preferences of transport modes in both countries turned towards the car, bicycle and walking. Communication modes changed with an overwhelming push to digitalisation, the use of ICT entered various fields of life, including work, leisure, education, communication. For Germany, there even might have been a behaviour shift in „a greater acceptance of technology“ (Grömling 2021)[56]. In Japan, it is considered to have a larger impact on changes in working styles. Work-style reforms aimed at pursuing a better work-life balance and improving labor productivity have long been attempted. In addition, it has long been pointed out that there is a need for further streamlining of administrative procedures and business through digitalization. These movements seem accelerating under the Covid-19 by the use of ICT.

Nevertheless: The estimation of the overall net effects of forced digitalisation (including electricity and resource consumption of the ICT-infrastructure) seems completely unclear in Germany and in Japan as well.

The decreased industry production, disturbed value chains and closed shops, restaurants, hotels, art facilities, public and private services etc. led to dramatic income losses, decreased consumption and increasing inequality. In Germany this is

[56]See https://www.intereconomics.eu/contents/year/2021/number/1/article/covid-19-and-the-growth-potential.html

discussed with growing concern and rising public awareness. This might have on important impact on energy consumption as well e.g. on the challenge how to fight energy poverty and how to step forward in the direction of more sustainable mobility for all and transportation justice. In this respect, it would be highly interesting to learn from the experiences of Japan concerning public transportation. In Japan, the share of public transportation is high, especially in metropolitan areas, which has contributed to improving the energy efficiency of the transport sector. However, the decline in passenger transport demand has created difficulties in the operation of public transportation, and if this situation persists, it will be necessary to review the management of public transportation.

5.4 Are German and Japanese recovery programs green enough?

“Governments have a once-in-a-lifetime opportunity to shape a better energy future“ (IEA, 2020, p.15). The IEA`s Special Report on Sustainable Recovery[57] developed a „Sustainable Development Plan: „The plan provides a significant boost to jobs and growth [...] and helps (to) put the world on a trajectory in line with international climate goals [...].” Compared to these goals and the detailed suggestions of the IEA „to shape a better energy future“ the national recovery programs of most countries could be improved. Against this background the question „are the German and Japanese recovery programs green enough, as well as effective enough as an economic stimulus?“ and how the programs in both countries can be improved should be analyzed in greater detail. Last not least this might create an important global signal: The world and especially the G 20 urgently need good practice examples and Japan in cooperation with Germany could take the lead!

[57] https://www.iea.org/reports/sustainable-recovery

For example, the "Energy Policy Tracker"[58] found that the G20 recovery programs against the economic consequences of the Corona crisis had flowed 374 billion dollars into the energy sector, of which around 205 billion dollars went into fossil fuels and only about $ 130 billion in "clean" energies. This undoubtly is bad news for climate mitigation!

The German and Japanese recovery packages include sustainability aspects, referring to research and development, the decarbonisation of automobiles, heat insulation of buildings, the decarbonisation of energy production, and ambitious strategies for the development of hydrogen technology: As has been shown about one third of the *German Recovery Program* is focused on the „Future package". But are the priorities and the allocated amount of public resources in line with current German decarbonisation targets and scenarios? This has not been analysed yet.

In the second *Japanese Recovery Program* climate change countermeasures are also included. However, the only identified support menu is solar PV installation for the manufacturing industry. A third stimulus package consists of three pillars: "Prevention measure against Covid-19 infection", "transformation of economic structure toward post-corona era", and "strengthening disaster resilience of the land." The second pillar clearly states policy for the realization of carbon neutrality. But will the expected renewed upswing in economic growth lead to a „green structural change" fostering climate protection?

In general: For no country, neither for Germany or Japan, it is sufficient just to record the quantity of the "green" expenditure shares within the recovery programs. Instead, the questions have to be answered whether and how far:

[58] Energy Policy Tracker 2 (September 2020) https://www.energypolicytracker.org/region/g20/

- green investments encourage sustainable structural change and accelerate climate protection ambitions?
- the net impact of technological shifts to digitalisation - including additional resources and electricity consumption - drive the decarbonisation e.g. by video conferencing, commuting traffic, home office, online shopping, E-learning, etc..?
- social learning and longterm behaviour changes are taken place e.g. concerning global supply chains, tourism, air travel, consumption patterns, leisure, culture etc.. ?
- policy learning changes the policy style e.g. to more proactive policy making and conducting (ecological) industrial policies ?

Especially, it remains to be seen to what extent the green spending activities are compatible with the priorities of current climate protection scenarios and strategies in both countries. And last not least: Can the comparison of the "green part" of recovery programs with their broad variety of different national priorities demonstrate that international cooperation and mutual learning could help to shape a common and better energy future?

6. Preparing a more comprehensive research program

With this background it seems to be advisable to conduct a more comprehensive study on the impacts of COVID 19 at the end of the year 2021 when more empirical data and analysis are available.

It has been demonstrated that there are many open research questions and the quicker research tries to give answers to them the better for our countries. As a follow up a Post Corona-19 study should compare latest overall economic projections of Germany and Japan and look into specific crisis induced structural changes and sector developments e.g. in industry, transportation and households. These economic projections should then be analysed concerning related energy consumption and GHG-emissions in the shortrun and beyond.

In this respect two basic research questions must be answered:
(1) Will the Corona pandemic accelerate climate mitigation strategies in Japan and Germany or will it cause a slash back, comparable to the situation after the financial crisis 2008/2009?
(2) Can the energy relevant impacts of the Corona pandemic be influenced by policies and measures and how does this contribute to decarbonisation strategies?

If in times of the „new normal“ (after the Corona pandemic) energy consumption and GHG-emissions would be coupled with economic development as in times of the „old normal“ a strong rebound effect back to old development pathways of GHG can be expected. Instead, it should be analysed whether the Corona pandemic has opened a window of opportunity for the departure from „business-as-usual“.

The interesting point for research on the energy impact of the Corona pandemic is that on the one hand *evidence based new developments* can be analysed concerning the impact on energy consumption and GHG-emissions, e.g. it is interesting to explain why renewable energy production seems to be less affected than traditional energy sources[59]. Apparently the limits of this part of research could *be the lack of empirical data.* Thus estimates whether the effects will be long lasting or only short run under the immediate impact of the Corona pandemic must

[59] One reason is obvious for countries, where green electricity is protected by FIT and/ or priority dispatching

sometimes focus on robust ranges of preliminary data. On the other hand it is interesting to analyse where *the pandemic has opended windows of opportunities* for politics, industry and the civil society to foster climate mitigation strategies which have been conceived to be impossible resp. publicly unacceptable before the pandemic; e.g. this might be possible with new concepts and strategies for a more sustainable and climate benign transportation system in Germany and Japan.

Japan and Germany are strongly interconnected with the global economy and international trade. Thus the comparison of energy and GHG-emissions in both countries has to start with analysing the embeddedness in global developments. For Germany as a Member of the European Union changes of the European policy context (e.g. the European Green Deal [60]) are especially important.

Conceptualizing a *common Japanese-German research programme* on the impact and possible longterm effects on energy consumption and GHG-emssions the following topics should be included:

- Overview and assessment of the international development concerning more ambitious or more reluctant decisions on climate protection during or induced by the Corona pandemic (e.g. US, EU, China, Japan)
- Review of latest post COVID-19 projections of global economic development and related energy consumption and GHG-emissions
- Comparing the current economic projections and related impacts of the Corona pandemic on total energy consumption and GHG – emissions (2019-2021) in Japan and Germany

[60] See for an overview https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/actions-being-taken-eu_en

- Comparison of the concepts and measures for refinancing / deleveraging of public debt caused by the recovery programs and possible impacts on inclusive and green growth
- Possible effects of the debt relief programs on the level of ambition and financial support for climate protection programs (e.g. for the decarbonisation of the building stock or industry)
- Change in public opinion about the importance of climate protection during the corona pandemic e.g. development and activities of social movements (Friday4Future etc.)
- Explaining similarities and differences of the perception, impacts and responses in Japan and Germany
- Status and outlook for long-lasting behavior change due to Covid-19 ant its impacts on energy consumption and GHG emission in Germany and Japan.
- Comparing the effects of crisis increased digitalisation e.g. on work, communication, mobility, education, consumption
- Preliminary estimate of increased energy and resource consumption caused by digitalisation based on existing studies

7. Conclusions

Even when vaccinations campaigns can stop the pandemic on a national scale, the global impacts will still heavily influence the interconnected economies of Germany and Japan eventually for years. Though a final national balance of the impact of COVID19 might not be realistic in 2021, many new answers are possible. Working on the energy transition of Japan and Germany since four years, the GJETC recognizes that the Corona crisis has caused profound new opportunities and challenges for both countries. Will it foster a chance for a Great Transformation towards climate neutral societies, or will there be a rebound back to the "Old

Normal” of unsustainable growth patterns? Further research should identify sectors, technologies, behaviour changes and fields of activities, where and how impacts of the crisis might contribute to foster the transition to a carbon neutral economy up to 2050. At the same time, it is necessary to look on possible counterproductive new developments and to propose a mix of policies and measures to mitigate them.

Facing the challenges of multiple crises such as climate change and the COVID 19 pandemic has also raised new questions for international research cooperation. We are happy that after four years of fruitful cooperation in the GJETC we were able to create trust in order to find joint solutions even for controversial and difficult topics of the energy transition. In this respect, the experience gained in analysing and overcoming the problems caused by COVID 19 will be a further encouragement to intensify our cooperation.

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二次利用未承諾リスト

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令和２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

一財）日本エネルギー経済研究所

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