Reporting obligation pursuant to Directive (EU) 2018/2001 concerning the potential of the use of energy from renewable sources

Assessment of the potential of energy from renewable sources and of the use of waste heat and cold in the heating and cooling sector in the Federal Republic of Germany.

Report by the Federal Republic of Germany to the Commission

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1 Zusammenfassung

Die Kommission sieht in Artikel 15 Absatz 7 der Erneuerbaren-Energien-Richtlinie (RED II) die Bewertung des Potenzials im Bereich der Energie aus erneuerbaren Quellen und der Nutzung von Abwärme und -kälte im Wärme- und Kältesektor vor.

Im Rahmen des vorliegenden Berichts werden die technischen und wirtschaftlichen Nachfragepotenziale im Bereich der Energien aus erneuerbaren Quellen und der Nutzung von Abwärme und -kälte im Wärme- und Kältesektor analysiert. Die Bewertung der Potenziale aus erneuerbaren Energien erfolgt für den Status quo sowie die Jahre 2030 und 2050. Dies geschieht in enger Abstimmung mit der umfassenden Bewertung zur Förderung von Effizienz bei der Wärme- und Kälteversorgung, die in der Richtlinie EU Energieeffizienzrichtlinie 2012/27/EU in Artikel 14 vorgesehen ist.

Die Analyse der erneuerbaren Potenziale für die Wärme- und Kälteversorgung in Deutschland erfolgt auf Basis einer Literaturanalyse, da bereits eine Vielzahl von Potenzialstudien vorliegt. Die Definition der einzelnen Wärmequellen erfolgt nach Artikel 2 Absatz 1 Satz 1 und Satz 9 der RED II. Wo relevant, werden weitere Differenzierungen nach Technologien bzw. Wärmequellen durchgeführt und abschließend je Wärmequelle zusammengefasst. Die weitere Differenzierung nach Technologien wird im Folgenden „Versorgungsoptionen“ genannt.

Tabelle 1 fasst die Ergebnisse der Ermittlung des Potenzials zusammen.

Bei den Potenzialen werden jeweils die technischen und wirtschaftlichen Nachfragepotenziale ausgewiesen, die in den Jahren 2030 und 2050 erschlossen werden könnten (nicht additiv). Es ist gekennzeichnet, ob sie sich auf Nutz- oder Endenergie beziehen.

Tabelle 1: Zusammenfassung der Potenziale aus erneuerbaren Energien und Abwärme und -kälte für die Wärme- und Kälteversorgung. (Quelle: Eigene Darstellung auf Basis der Analysen in den nachfolgenden Abschnitten)

		Technische Potenziale [TWh]				**Wirtschaftliche Potenziale [TWh]**			
		2030		**2050**		**2030**		**2050**	
		von	**bis**	**von**	**bis**	**von**	**bis**	**von**	**bis**
Sonnenenergie*									
	Dezentrale Solarthermie	98*	120*	73*	108*	22**	22**	43**	43**
	Großflächensolarthermie	94**	94**	94**	94**	8*	29*	10*	65*
Geothermie									
	Tiefen-geothermie**	37	108	31	88	18	46	9	32
	Oberflächennahe Geothermie***	289	652	233	594	27	170	49	294
	Grubenwasser**	8	8	2	2	4	4	2	2
Biomasse davon[1]:**						**60**	**185**	**16**	**187**
	Deponiegas					0	0		
	Klärgas					3	3		
	Biogas					0	65		
Umgebungsenergie									
	Dezentrale Nutzung Umgebungsluft mittels Wärmepumpen***	260	267	176	242	11	85	66	242
	Zentrale Nutzung Umgebungsluft mittels Wärmepumpen***	318	531	425	531	44	73	76	95
	Oberflächengewässer**	110	114	90	102	81	82	49	66
	Abwasser*	36	46	24	38	5	7	16	16
Abwärme und Kälte									
	Industrielle Abwärme zur netzgebundenen Nutzung*	23	29	17	21	19	21	14	15
	Abwärme aus Wärmekraftwerken	Nur theoretische Potenzialanalysen verfügbar							
	Abwärme aus Abfallverbrennung*	16	17			16	17		
	Abwärme des tertiären Sektors	Relevant, jedoch keine Potenzialanalysen verfügbar							

*Bezogen auf Nutzenergie, **Bezogen auf Endenergie *** Wärmebereitstellung mit Wärmepumpen, inkl. Stromanteil

Bei der Interpretation müssen folgende Grenzen der Potenzialanalyse berücksichtigt werden:

1. Die Summe der ermittelten Potenziale übersteigt den aktuellen bzw. zukünftigen Energieverbrauch für Wärme. Dabei ist zu berücksichtigen, dass ein Aufsummieren der Einzelpotenziale zu einem Gesamtpotenzial methodisch nicht zielführend ist, da sich verschiedene Versorgungsoptionen gegenseitig bedingen oder ausschließen.

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[1] Im Bereich der Biomasse sind keine technischen Potenziale ausgewiesen, da in diesem Bereich in den verschiedenen Analysen und Studien aufgrund der Nutzungskonkurrenz zu anderen Sektoren keine Allokation vorgenommen wird. Weitere Ausführungen hierzu in der Zusammenfassung und im Abschnitt 5.

2. Im Bereich der leitungsgebundenen Energieversorgung ist bei der Erschließung der Potenziale die räumliche Komponente ausschlaggebend: Potenziale können nur bei angemessener Nähe zu den Wärmesenken genutzt werden. Gerade hier überlagern sich die Potenziale häufig räumlich und ein Aufaddieren der Einzelpotenziale ist nicht zweckmäßig. Wird ein Wärmenetz beispielsweise bereits über thermische Abfallbehandlungsanlagen versorgt, ist die Integration von erneuerbaren Energien oder Abwärme, die primär in der Grundlast eingesetzt wird (z. B. Solarthermie oder industrielle Abwärme) oft nicht mehr möglich, und die Potenziale können somit nicht genutzt werden.

3. Zusätzlich zu den leitungsgebundenen Potenzialen bestehen parallel dezentrale Potenziale, die aufgrund einer quantitativ bzw. qualitativ (räumlich, technologisch, etc.) anders gelagerten Verbraucherstruktur nicht allesamt erschlossen werden können.

4. Einige Technologien, wie beispielsweise die solare Wärmeerzeugung, brauchen zusätzlich einen Spitzenlasterzeuger bzw. Hauptwärmeerzeuger. Dies ist dadurch bedingt, dass eine monovalente Deckung des Wärmebedarfs je nach Einsatzfall zu überproportional höheren Kosten führen kann (Beispiel: saisonale Speicherung von Solarwärme) und deswegen wirtschaftlich nicht darstellbar ist.

5. Wärmepumpen können grundsätzlich mit anderen Versorgungsoptionen kombiniert werden. Es besteht jedoch die Gefahr, dass sich die Systeme bezüglich eines optimierten Einsatzes überschneiden und somit höhere Wärmegestehungskosten verursachen.

6. Die zukünftigen Potenziale von Biomasse für die Wärme- und Kälteversorgung weisen eine erhebliche Schwankungsbreite auf. Während in Deutschland mit ca. 150 TWh/a gegenwärtig noch ca. 85 % der erneuerbaren Wärme aus Biomasse bereitgestellt werden, ist zukünftig tendenziell eher von einer deutlichen Verringerung dieses Anteils und – aufgrund der Nutzungskonkurrenz mit anderen Sektoren – auch des absoluten Biomassepotenzials für die Wärme- und Kälteversorgung auszugehen (siehe Abschnitt 5.3). Insofern sollte eine Orientierung tendenziell eher am unteren Bereich der in Tabelle 1 ausgewiesenen Biomasse-Bandbreiten erfolgen. Eine naturschutzfachliche Betrachtung entsprechend dem Methodenhandbuch der DBFZ wurde ebenso nicht vorgenommen.

7. Die Potenziale stehen in Zusammenhang mit der Effizienz des Gebäudebestands bzw. den Effizienzentwicklungen in der Industrie: So steigen beispielsweise die möglichen Einsatzfälle von Solarenergie und Wärmepumpen auf Basis verschiedener Wärmequellen mit höherer Effizienz des Gebäudebestands, auch wenn das energetische Potenzial sinken kann. Umgekehrt sinken die Potenziale einer wärmenetzgebundenen Versorgung bei sinkenden Gebäudeenergieverbräuchen, wenn nicht gleichzeitig die Anschlüsse an das Netz erhöht werden. Eine Bewertung der Versorgungsoptionen im Hinblick auf die Einsetzbarkeit zur Erfüllung von Klimaschutzanforderungen oder sonstigen Umweltzielen wird nicht vorgenommen, auch hierdurch werden Potenziale ggf. eingeschränkt.

8. Da die Potenziale auf Basis von Literaturrecherchen ermittelt wurden, variieren die in den Studien angesetzten Rahmenbedingungen hinsichtlich Energieeffizienz, Fernwärmeabsatz, berücksichtigter Gebäudetypen und energiewirtschaftlicher Rahmenbedingungen. Die entsprechenden wesentlichen Treiber bei der Ermittlung der Potenziale sind in den jeweiligen Abschnitten ausgeführt.

9. Bei den ermittelten wirtschaftlichen Potenzialen ist darauf hinzuweisen, dass diese stark von den energiewirtschaftlichen und -politischen Rahmenbedingungen abhängen.

Sowohl der jetzige Rahmen als auch die von den jeweiligen Autoren in den Studien unterstellten Entwicklungen beeinflussen die wirtschaftlichen Potenziale wesentlich:

- Die Berücksichtigung eines ausreichend hohen CO_2-Preises für konventionelle Wärmeerzeugung erhöht die Kosten für die Referenztechnologie (meist gasbasierte Brennwerttechnologien in Gebäuden) und kann somit zur Steigerung der entsprechenden wirtschaftlichen EE-Potenziale beitragen.
- Eine Neugestaltung der Steuern und Umlagen auf Strom kann zu höheren wirtschaftlichen Potenzialen für Wärmepumpen führen.
- Investitionsförderungen im Bereich erneuerbarer Fernwärmeerzeugung steigern die Investitionssicherheit von Unternehmen und können sich wesentlich auf die wirtschaftlichen Potenziale der erneuerbaren Fernwärme auswirken.
- Weitere programminterne Kostenprojektionen, wie zum Beispiel die Entwicklung von Anlagenkosten durch Skaleneffekte, oder modellendogene Entscheidungsroutinen beeinflussen die Ergebnisse hinsichtlich der wirtschaftlichen Potenziale, können aber nach Veröffentlichung der grundlegenden Studien aufgrund der durchgeführten Modellierungen nicht adaptiert werden.
- Vor diesem Hintergrund ist zukünftig auf Basis weiterer Entwicklungen und Erkenntnissen davon auszugehen, dass sich die wirtschaftlichen Potenziale verändern können – sowohl eine Erhöhung als auch eine Reduktion kann nicht ausgeschlossen werden.

Ergebnisse und Interpretation

Im Bereich der **Sonnenenergie** wurden dezentrale Solarthermie und Photovoltaikanlagen sowie Großflächen-Solarthermieanlagen analysiert. Sowohl dezentrale Solarthermieanlagen im Gebäudebestand als auch Großflächen-Solarthermieanlage zur Nutzung in Wärmenetzen bedürfen der Ergänzung durch einen Haupt- oder Spitzenlastkessen. Dabei ist bei der **dezentralen Solarthermie** das Potenzial konventioneller Solarthermieanlagen dargestellt. Anlagen mit extrem großen oder saisonalen Speichern sind nicht berücksichtigt. Die limitierende Größe bei der Potenzialermittlung ist der maximale Deckungsgrad, den Solarthermieanlagen erbringen können. Das technische Potenzial bezieht sich auf solare Nutzwärme in Wohn- und Nichtwohngebäuden und berücksichtigt deren Entwicklung in zwei Szenarien. Das wirtschaftliche Potenzial liegt deutlich unter dem technischen Potenzial. Es wird stark von den Wärmegestehungskosten des erforderlichen Spitzenlast- bzw. Hauptwärmeerzeugers beeinflusst. Das wirtschaftliche Potenzial beträgt rund das Dreifache des aktuellen Solarthermie-Ausbaus. Damit kann Solarthermie einen wichtigen Beitrag zur Entlastung anderer erneuerbarer Energien liefern.
Für die Bestimmung des Potenzials aus **Photovoltaik** (PV) speziell zur Wärmeerzeugung wurde das Potenzial für Photovoltaik auf Dachflächen und Fassaden insgesamt analysiert, jedoch keine Allokation auf den Wärme- und Kältesektor vorgenommen, da über die Wärmeerzeugung hinaus PV auf Gebäuden auch EE-Strom verbrauchsnah bereitstellen kann.
Während das technische Potenzial der **Großflächensolarthermie** mit 94 TWh für die Jahre 2030 und 2050 im mittleren Bereich liegt, ist das ermittelte wirtschaftliche Potenzial mit 8 bis 29 TWh im Jahr 2030 geringer. Das technische Potenzial ist allerdings stark abhängig von der zu Grunde gelegten Flächenkulisse. Die relativ große Bandbreite bezüglich des wirtschaftlichen Potenzials resultiert aus unterschiedlichen Annahmen zur Entwicklung des Wärmenetzpotenzials und der solaren Deckungsgrade (u. a. bedingt durch den Einsatz von Wärmespeichern). Aktuell erzeugen ca. 40 großflächige Solarthermieanlagen rund 42 GWh Wärme jährlich, es besteht demnach noch ein sehr hohes Ausbaupotenzial. Die Konkurrenz zu anderen Wärmeerzeugern (z. B. Abfallverbrennung) und die Flächeninanspruchnahme sowie die Konkurrenzsituation mit der PV um Freiflächen können hemmende Faktoren beim Ausbau zentraler großflächiger Solarthermieanlagen sein. Solare Deckungsgrade in

Wärmenetzen können insbesondere durch die Integration saisonaler Wärmespeicher (z. B. Behälter-, Erdbecken- und Aquifer-Wärmespeicher) erhöht werden.

Im Bereich der **Geothermie** wurde die Tiefengeothermie, die oberflächennahe Geothermie in der zentralen und dezentralen Nutzung sowie das Potenzial von Grubenwasser näher beleuchtet. Bei der **Tiefengeothermie** wurden hydrothermale Potenziale in Deutschland für eine passive und aktive Nutzung mittels Wärmepumpen analysiert. Dabei belaufen sich die technischen Nachfragepotenziale – je nach Art der Einbindung – auf 37 bis 108 TWh im Jahr 2030 und reduzieren sich aufgrund des Rückgangs des Wärmebedarfs auf 31 bis 88 TWh im Jahr 2050. Mit großen Unsicherheiten sind indes die dargestellten wirtschaftlichen Potenziale in Wärmenetzen zur Versorgung von Wohn- und Nichtwohngebäuden behaftet. Die Abschätzung der Wirtschaftlichkeit wurde entsprechend Jochum et al. (2017) über einen pauschalen, methodisch vereinfachenden Grenzwert der spezifischen Wärmegestehungskosten für hydrothermale tiefe Geothermie von <75 EUR/MWh_{th} abgeleitet.

Der limitierende Faktor für die Nutzung von **oberflächennaher Geothermie** mittels dezentraler Wärmepumpen in Gebäuden ist das Verhältnis von verfügbarer Fläche für Geothermie zum lokalen Wärmebedarf. Vor allem in dichter urbaner Bebauung können dezentrale Erdwärmepumpen oft nicht eingesetzt werden. Abseits dichter Bebauung erlaubt das technische Potenzial oberflächennaher Geothermie die Versorgung eines bedeutenden Anteils des Gebäudebestands, wenn die Gebäude eine Mindesteffizienz einhalten. Die zentrale Nutzung ist vor allem durch die möglichen Fernwärmepotenziale limitiert, da ein Einsatz von zentralen Wärmepumpen auf Basis von oberflächennaher Geothermie an vielen Standorten möglich ist. Weitere Einschränkungen bestehen zudem hinsichtlich der Flächenverfügbarkeit. Die Potenzialabschätzung zeigt technische Potenziale bis zu 650 TWh im Jahr 2030 und rd. 590 TWh im Jahr 2050. Die wirtschaftlichen Potenziale sind aufgrund der hohen Unsicherheit hinsichtlich der zukünftigen Entwicklungen vorsichtig zu interpretieren und werden mit bis zu 170 TWh für das Jahr 2030 bzw. bis zu 294 TWh im Jahr 2050 ausgewiesen. Dabei sind bereits förderlichere Rahmenbedingungen im Jahr 2050 unterstellt, jedoch sind in den Analysen keine Annahmen zu den jeweiligen spezifischen Maßnahmen und Rahmenbedingungen benannt.

Das thermische Potenzial von **Grubenwasser** zur Wärme- bzw. Kälteerzeugung in Deutschland ist im Vergleich zu den anderen Potenzialen gering (technisches Potenzial von 8 TWh im Jahr 2030 und 2 TWh im Jahr 2050). In Zukunft wird sich das Potenzial zudem weiter reduzieren, da die bestehenden Braunkohletagebaue stillgelegt werden und dort kein Sümpfungswasser zur thermischen Nutzung mehr anfällt. Die Potenziale sind gebietsweise sehr unterschiedlich, insbesondere in den ehemaligen Steinkohlerevieren in Nordrhein-Westfalen, im Saarland und in Sachsen bestehen auch langfristig Potenziale.

Auf Basis der Analyse von umfangreichen **Biomassepotenzialstudien** wurden das Flächenpotenzial und das in den Studien ermittelte Potenzial an Anbaubiomasse sowie Rest- und Abfallstoffen zusammengestellt. Bei der Potenzialanalyse von Biomasse für die Wärme- und Kälteversorgung müssen konkurrierende Biomassenutzungen in anderen Sektoren mitberücksichtigt werden. Im Rahmen von Energieszenario-Studien wurden auf Basis unterschiedlichster Rahmendaten und -annahmen in umfangreichen Modellierungen Allokationen der Biomasse auf die einzelnen Verbrauchssektoren vorgenommen und die entsprechenden wirtschaftlichen Potenziale ausgewiesen. Die Ergebnisse der Analyse zeigen eine Bandbreite der wirtschaftlichen Potenziale von Biomasse von 60 bis 185 TWh im Jahr 2030 und von 16 bis rd. 187 TWh im Jahr 2050. Angesichts der heutigen Nutzung in Höhe von ca. 150 TWh/a ist also nicht von einer zukünftigen Steigerung des Gesamt-Biomassepotenzials für die Wärme- und Kälteversorgung auszugehen, eher im Gegenteil (siehe Abschnitt 5.3). Insofern sollte eine Orientierung tendenziell eher am unteren Bereich der in Tabelle 1 ausgewiesenen Biomasse-Bandbreiten erfolgen.

Im Bereich der **Umgebungsenergie** wurden sowohl zentrale als auch dezentrale Wärmepumpen mit der Wärmequelle Außenluft beleuchtet sowie die Potenziale von Oberflächengewässer-Wärmepumpen und Abwasser-Wärmepumpen dargestellt.

Die Nutzung von Umgebungsenergie mittels **dezentraler Luft-Wärmepumpen in Gebäuden** hat das höchste wirtschaftliche Potenzial der gezeigten dezentralen erneuerbaren Energien im Jahr 2050 (bis zu 85 TWh im Jahr 2030 und 242 TWh im Jahr 2050). Das technische Potenzial wird vorrangig durch die Effizienz der Gebäude begrenzt. Ist es möglich, den Wärmebedarf großflächig unter 90 kWh/m²a zu senken, ist ein breiter Einsatz von Luft-Wärmepumpen möglich und auch aus wirtschaftlicher Sicht umsetzbar.

Für **zentrale Luftwärmepumpen** in Fernwärmenetzen ergibt sich in der durchgeführten Potenzialanalyse ein sehr hohes technisches Potenzial in Höhe von 318 bis 531 TWh im Jahr 2030 bzw. 425 bis 531 TWh im Jahr 2050, da standortunabhängig mit geringen Restriktionen die Erschließung der Wärmequelle ‚Luft' möglich ist. Aktuell stellen die hohen Vorlauftemperaturen der Wärmenetze jedoch ein Hindernis für die Einbindung von zentralen Luftwärmepumpen dar. Eine effiziente Einbindung von Luftwärmepumpen wird mit der Transformation hin zu niedrigen Netztemperaturen in Zukunft erleichtert, dann ist mit der Außenluft als zentraler Wärmequelle die Erschließung des insgesamt größten Potenzials möglich.

Die Potenziale zur thermischen Nutzung von **Oberflächengewässern in Wärmenetzen** liegen verglichen mit den anderen Wärmequellen im mittleren Bereich. Der Unterschied zwischen technischen und wirtschaftlichen Potenzialen ist relativ gering. In Deutschland werden sie aktuell noch kaum ausgeschöpft. Die Erschließung von Seen, Flüssen oder dem Meer mittels Wärmepumpen ist nur wirtschaftlich, wenn entsprechend große Wärmesenken in unmittelbarer Nähe zu den Gewässern verortet sind. Auch die hohen Vorlauftemperaturen in bestehenden Wärmenetzen sowie der geringe Bekanntheitsgrad der Technologie und die nicht einheitlich geregelten wasserrechtlichen Bedingungen für die Genehmigungsfähigkeit hemmen die Etablierung der Erschließung von Oberflächengewässern.

Die Potenziale aus Energie aus **Abwasser in Wärmenetzen** ergeben sich durch die energetische Nutzung des ungereinigten Abwassers in der Kanalisation und durch die Nutzung des Abwassers nach der Kläranlage. Die technischen Potenziale betragen im Jahr 2030 bis zu 46 TWh, im Jahr 2050 reduziert sich das Potenzial aufgrund der angenommen Effizienzsteigerung im Gebäudebestand auf 38 TWh.

Bei der Analyse der Potenziale aus **Abwärme und -kälte** sind die Potenziale aus industrieller Abwärme und -kälte, jener aus Wärmekraftwerken und Abfallverbrennungsanlagen und jene aus dem tertiären Sektor zu analysieren. **Industrielle Abwärme und -kälte** kann sowohl in der allgemeinen Wärmeversorgung als auch für die innerbetriebliche Nutzung herangezogen werden. Auf Basis von kleinräumigen Analysen wurde das Potenzial für die netzgebundene Nutzung in Wärmenetzen analysiert und bis zu 21 TWh wirtschaftliches Potenzial 2030 bzw. 15 TWh 2050 ermittelt. Unsicherheiten bestehen jedoch bei der Abschätzung des langfristig verfügbaren Angebotspotenzials, das maßgeblich durch wirtschaftliche Entwicklungen (Standortwahl, Betriebsschließungen) und technologischen Fortschritt (z. B. Verfahrensumstellungen, Effizienzmaßnahmen) beeinflusst wird. In den Analysen ist aufgrund von Datenlücken jedoch z. B. das Potenzial aus einigen Medienströmen wie Prozessabwasser, Prozessabluft oder explizit „vernichtete Abwärme" aus Kühlprozessen aufgrund von mangelnder Datenbasis nicht abgebildet. In vielen Unternehmen werden zentrale Kühlanlagen für die Produktion verwendet, die Kühlwassertemperaturen von 35–40°C aufweisen. Das Kühlwasser könnte als Wärmequelle für Großwärmepumpen herangezogen werden

und somit für die Wärme- und Kälteversorgung erschlossen werden. Auch die innerbetriebliche Nutzung als Effizienzmaßnahme könnte die Potenziale weiter erhöhen.
Bei der Ermittlung der Potenziale aus **thermischen Abfallbehandlungsanlagen** wurde der biogene Anteil bei der Berechnung abgezogen, um Dopplung der Potenziale mit jenen im Bereich Biomasse zu vermeiden. Unter Berücksichtigung der Potenziale in Müllverbrennungsanlagen, Ersatzbrennstoffkraftwerken und Sondermüllverbrennungsanlagen belaufen sich die fossil-stämmigen Potenziale auf rd. 16 bis 17 TWh im Jahr 2030. Analysen bis 2050 können aufgrund großer Unsicherheiten in der Abfallwirtschaft nicht robust durchgeführt werden. Auch das Potenzial an Abwärme aus dem **tertiären Sektor** kann für eine effiziente Wärme- und Kälteversorgung genutzt werden. Hier sind jedoch keine flächendeckenden Potenzialanalysen in Deutschland oder der EU bekannt.

Abbildung 1 und Abbildung 2 stellen die eben diskutierten Ergebnisse in Form der aus den unterschiedlichen Literaturquellen entnommenen Bandbreite für das Jahr 2030 grafisch dar – wenn verfügbar werden zusätzlich Werte für die gegenwärtige Potenzialausschöpfung dargestellt. Abbildung 3 und Abbildung 4 zeigen die Ergebnisse für das Jahr 2050.

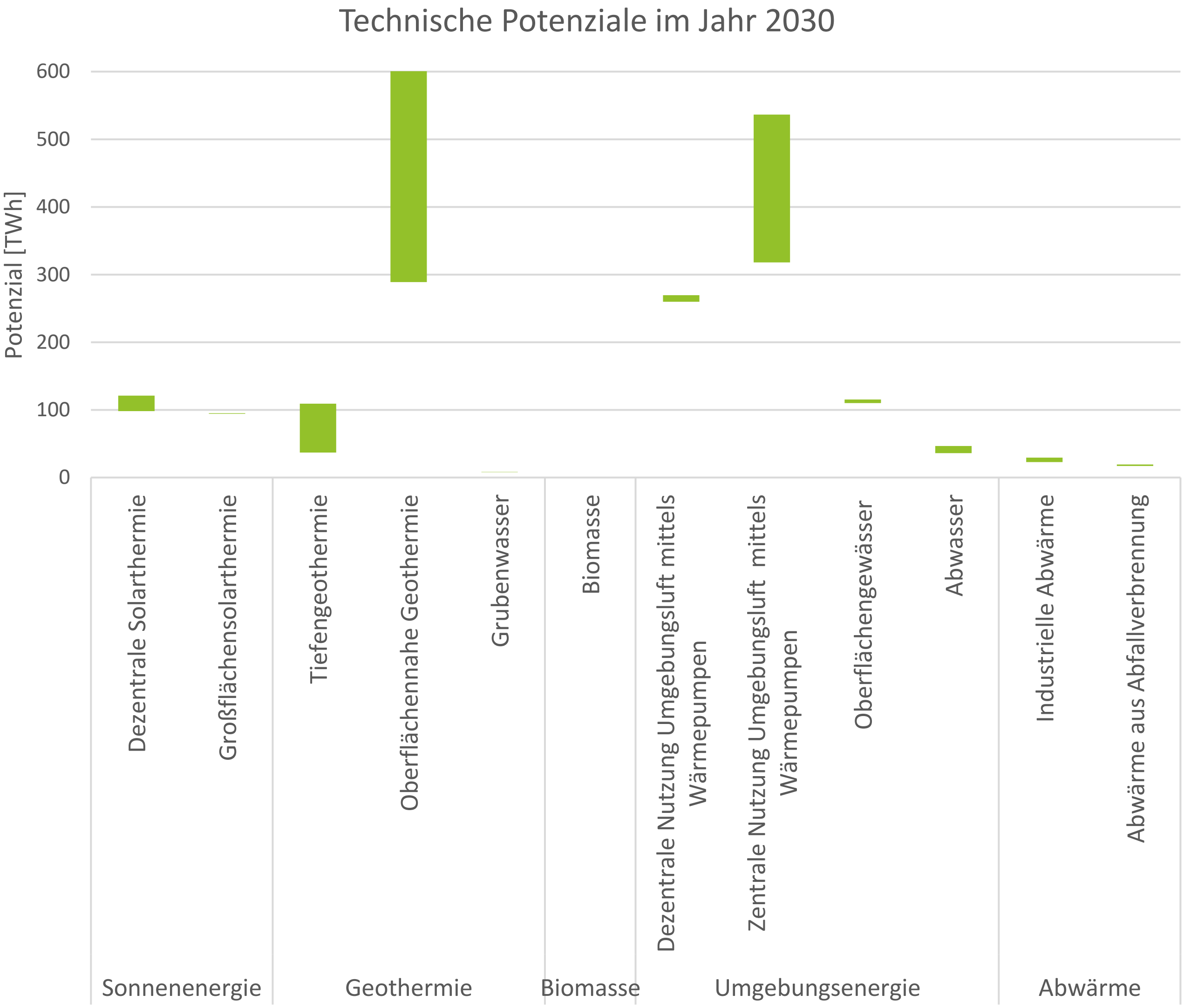

Abbildung 1: Darstellung der technischen Potenziale aus erneuerbaren Energien für die Wärme- und Kälteversorgung im Jahr 2030 (Quelle: Eigene Darstellung)

Die Darstellung der technischen Potenziale im Jahr 2030 in Abbildung 1 zeigt die Bandbreite der Potenziale der einzelnen Versorgungsoptionen (als Kombination aus Wärmequelle und Technologie) als Ergebnis der Analysen. Im Bereich Biomasse können keine technischen Potenziale ausgewiesen werden, da es für die verschiedenen Bioenergieträger verschiedene Nutzungsmöglichkeiten im Energiesystem (Strom, Wärme, Kraftstoff) gibt. In vielen klassischen Biomassepotenzialstudien wird jedoch keine Allokation (Zuordnung) des technischen Potenzials auf die einzelnen Verbrauchssektoren vorgenommen und damit kein Bioenergiepotenzial auf Endenergie-Ebene ausgewiesen. Weitere Datenlücken bestehen bei der Abwärme aus Wärmekraftwerken und der Abwärme des tertiären Sektors: Während bei der Abwärme aus Wärmekraftwerken das theoretische Potenzial ermittelt werden kann, wurde in keiner Studie das technische oder wirtschaftliche Potenzial analysiert. Zudem unterliegt der Kraftwerkspark auf Grund des Kohleausstiegs derzeit einem grundlegenden Umbau. Auch die Potenziale aus Abwärme des tertiären Sektors (u. a. Datencenter) standen bundesweit noch nicht im Fokus einzelner Studien.

In Abbildung 2 sind die ermittelten wirtschaftlichen Potenziale im Jahr 2030 grafisch dargestellt. Für dezentrale Solarthermie, Tiefengeothermie, Biomasse und Abfallverbrennung werden die ermittelten Potenziale dem Endenergieverbrauch des entsprechenden Energieträgers im Jahr 2019 auf Basis von AGEE-Stat (2020) gegenübergestellt: Es ist ersichtlich, dass im Bereich Biomasse und Abwärme aus Abfallverbrennung bereits ein Großteil der Potenziale für die Wärmeversorgung genutzt werden. Im Bereich dezentraler Solarthermie und Tiefengeothermie kann noch ein Großteil der Potenziale zusätzlich erschlossen werden. Rund 15 TWh des Endenergieverbrauchs im Sektor Wärme und Kälte wurden im Jahr 2019 darüber hinaus durch oberflächennahe Geothermie und Umgebungswärme gedeckt, was jedoch aufgrund der unterschiedlichen Bilanzierungsgrenzen in der Grafik nicht dargestellt werden kann: Stellt man dies den Potenzialen der oberflächennahen Geothermie sowie der dezentralen und zentralen Nutzung von Wärmepumpen gegenüber, zeigt sich, dass hier noch große ungenutzte Potenziale vorliegen.

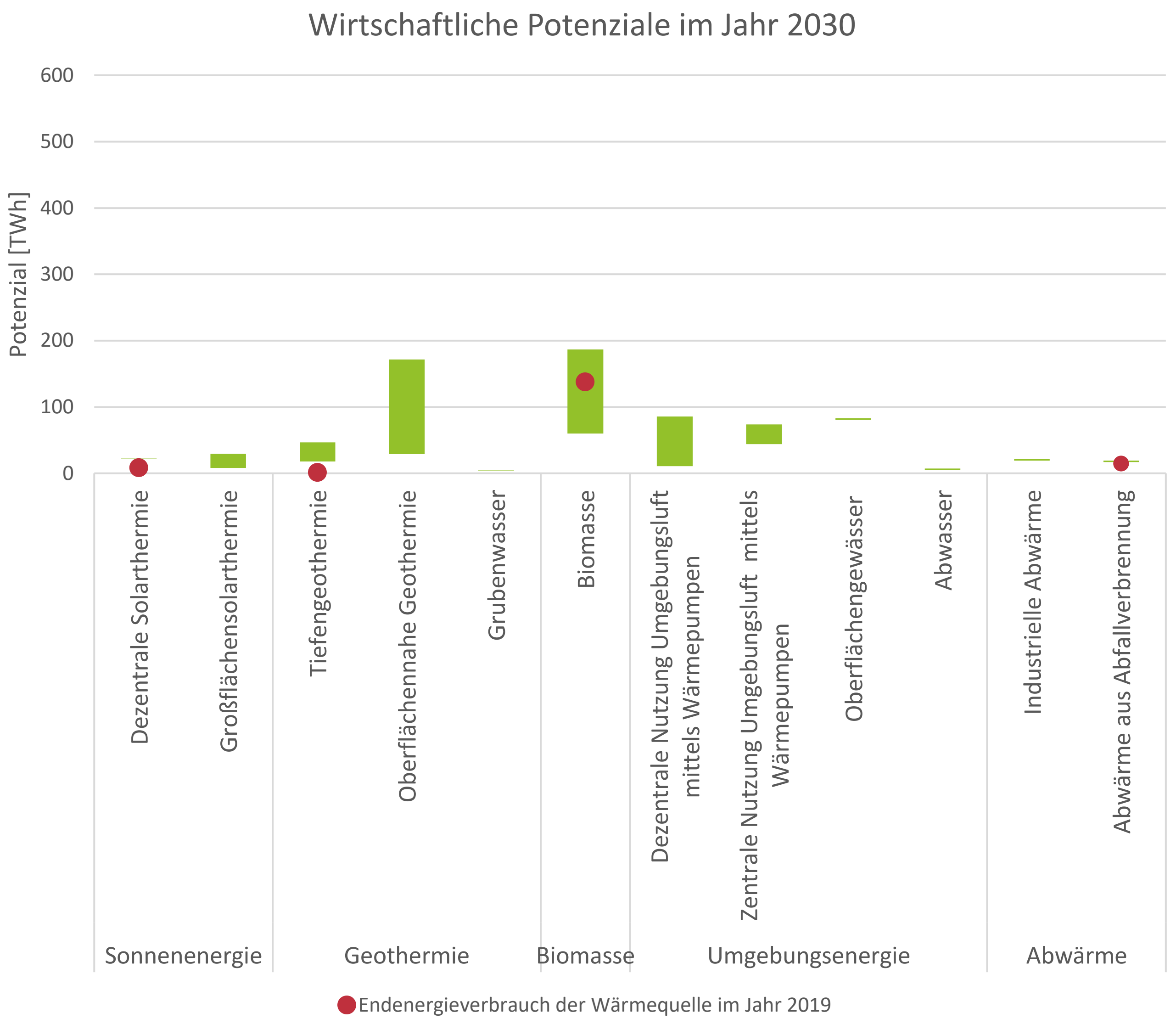

Abbildung 2: Darstellung der wirtschaftlichen Potenziale aus erneuerbaren Energien für die Wärme- und Kälteversorgung im Jahr 2030 (Quelle: Eigene Darstellung; Endenergieverbrauch aus (AGEE-Stat, 2020))

Die Darstellung der technischen Potenziale im Jahr 2050 in Abbildung 3 zeigt die Bandbreite der Potenziale der einzelnen Versorgungsoptionen (als Kombination aus Wärmequelle und Technologie) als Ergebnis der Analyse analog zu der Darstellung für das Jahr 2030.

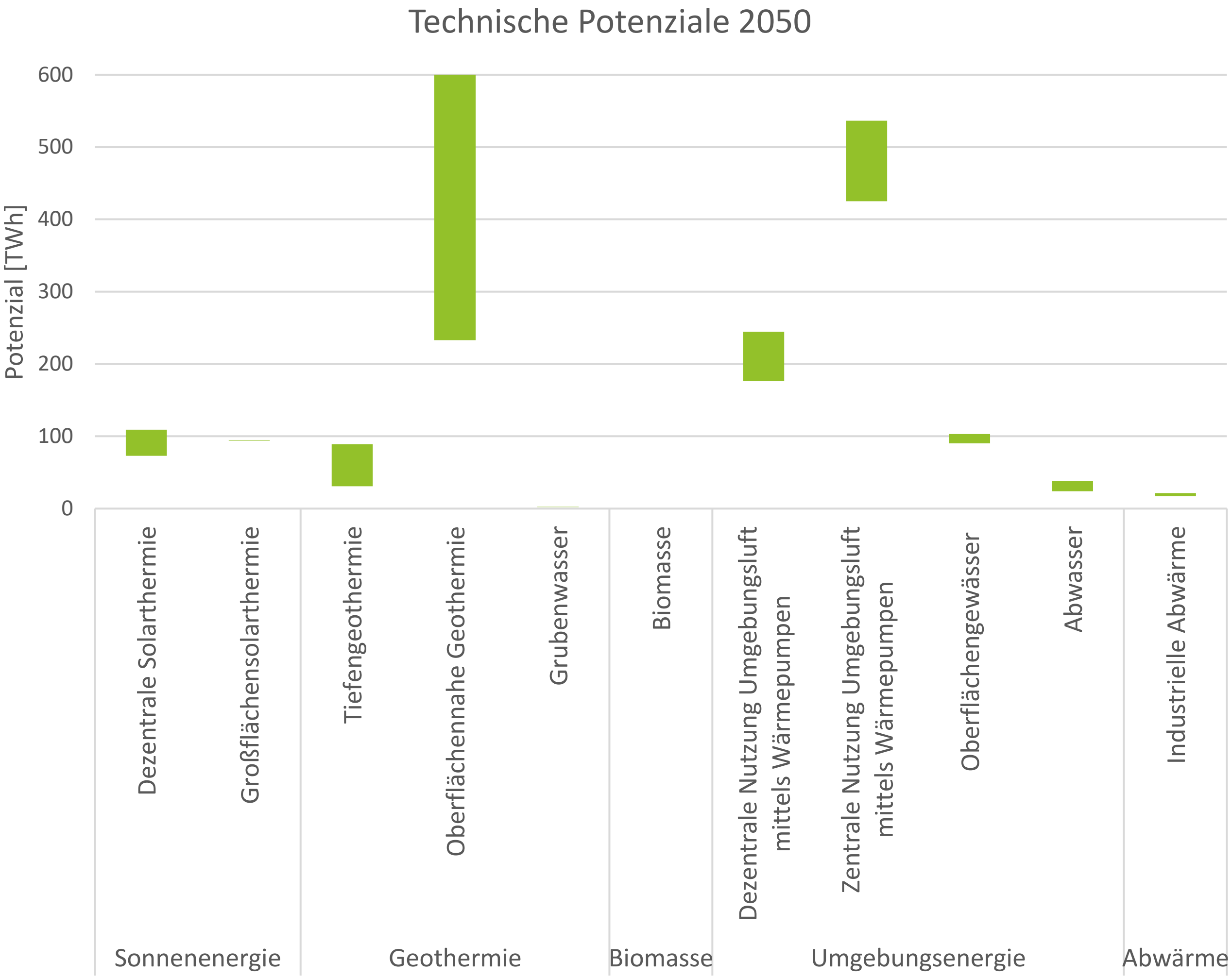

Abbildung 3: Darstellung der technischen Potenziale aus erneuerbaren Energien für die Wärme- und Kälteversorgung im Jahr 2050 (Quelle: Eigene Darstellung)

In Abbildung 4 sind die ermittelten wirtschaftlichen Potenziale im Jahr 2050 grafisch dargestellt. Für dezentrale Solarthermie, Tiefengeothermie, Biomasse und Abfallverbrennung werden die ermittelten Potenziale erneut dem Endenergieverbrauch des entsprechenden Energieträgers im Jahr 2019 auf Basis von AGEE-Stat (2020) gegenübergestellt. Allgemein sind im Jahr 2050 größere Bandbreiten als im Jahr 2030 ersichtlich.

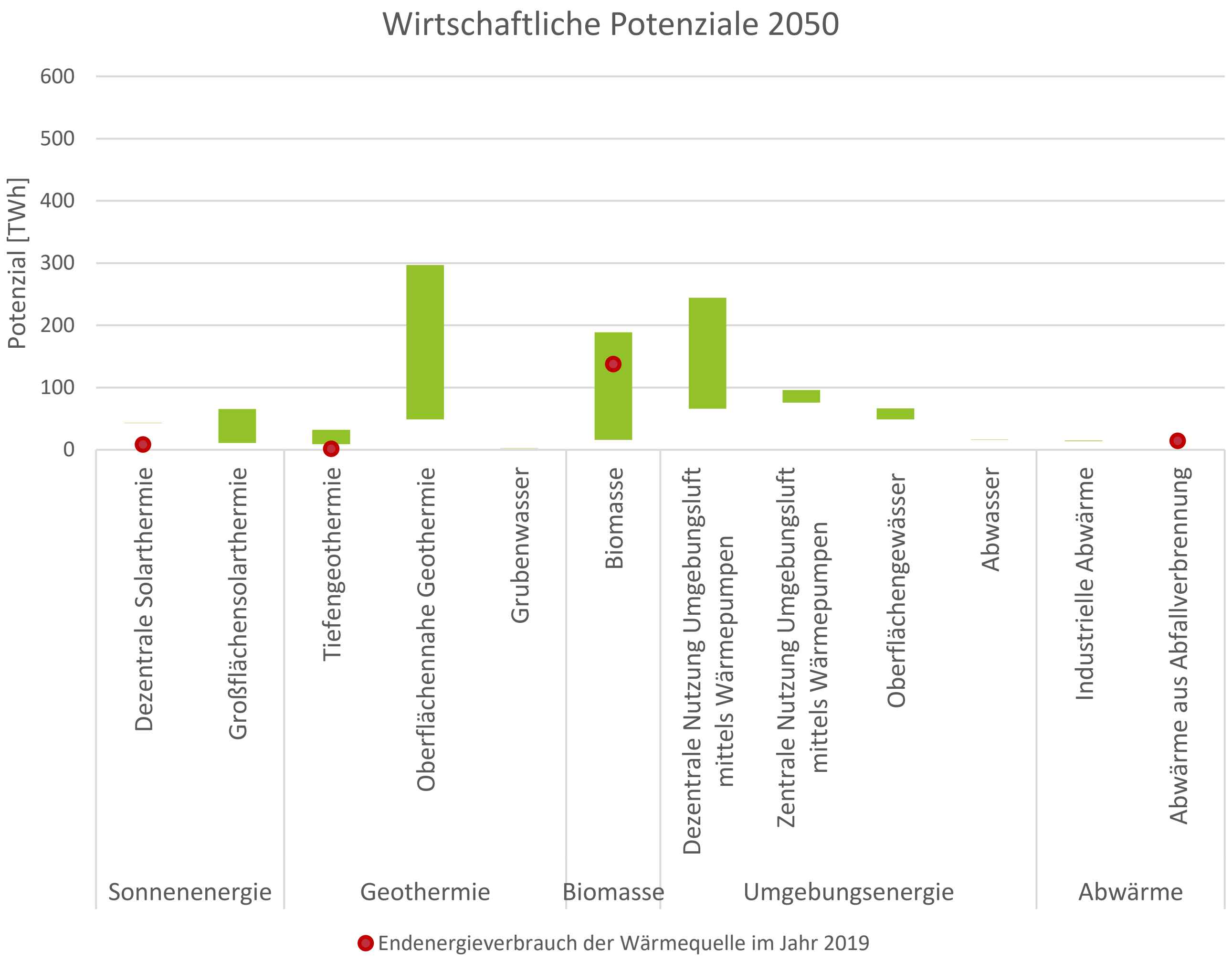

Abbildung 4: Darstellung der wirtschaftlichen Potenziale aus erneuerbaren Energien für die Wärme- und Kälteversorgung im Jahr 2050 (Quelle: Eigene Darstellung; Endenergieverbrauch aus (AGEE-Stat, 2020))

2 Executive Summary

The Commission provides in Article 15 (7) of the Renewable Energy Directive (RED II) for the assessment of the potential of energy from renewable sources and the use of waste heat and cold in the heating and cooling sector.

The present report assesses the technical and economic demand potential in the field of energy from renewable sources and the use of waste heat and cold in the heating and cooling sector. The renewable potentials for the status quo and for the years 2030 and 2050 are identified. This will be done in close coordination with the comprehensive assessment for the promotion of efficiency in heating and cooling supply as provided in Article 14 of the EU Energy Efficiency Directive 2012/27/EU.

The analysis of the renewable potentials for heating and cooling supply in Germany is based on an analysis of the literature, since many potential studies are already available. The definitions follow Article 2 (1) of the RED II. Where relevant, further differentiations by technologies or heat sources are carried out and finally summarised for each heat source. The further differentiation by technologies is referred to below as "supply options".

Table 2 summarises the results of the determination of the potential.

A distinction is made between the technical and economic demand potentials that could be made accessible in 2030 and 2050 (not additive). It is indicated whether the potentials relate to useful or final energy demand.

Table 2: Summary of potentials from renewable energies and waste heat and cold for heating and cooling (Source: Own illustration, based on the analysis described in the following chapters)

		Technical potentials [TWh]				Economic potentials [TWh]			
		2030		2050		2030		2050	
		From	**To**	**From**	**To**	**From**	**To**	**From**	**To**
Solar Energy									
	Decentral solarthermal energy	98*	120*	73*	108*	22**	22**	43**	43**
	Large-scale solarthermal energy	94**	94**	94**	94**	8*	29*	10*	65*
Geothermal Energy									
	Deep geothermal energy**	37	108	31	88	18	46	9	32
	Near surface geothermal energy***	289	652	233	594	27	170	49	294
	Mine water**	8	8	2	2	4	4	2	2
Biomass thereof[1] :**						**60**	**185**	**16**	**187**
	Landfill gas					0	0		
	Sewage gas					3	3		
	biogas					0	65		
Ambient energy									
	Decentralised use of ambient air using heat pumps***	260	267	176	242	11	85	66	242
	Centralised use of ambient air using heat pumps***	318	531	425	531	44	73	76	95
	Surface water**	110	114	90	102	81	82	49	66
	Waste water*	36	46	24	38	5	7	16	16
Waste heat and cold									
	Industrial waste heat and cold*	23	29	17	21	19	21	14	15
	Waste heat from thermal power plant	Only theoretical potential analyses available							
	Waste heat from waste incineration plants*	16	17			16	17		
	Waste heat from tertiary sector	Relevant, but no potential analyses available							

*In relation to useful energy demand, **In relation to final energy demand, *** Heat supply with heat pumps, including electricity

The following limits of the potential analysis must be taken into account in the interpretation:

1. The sum of the identified potentials exceeds the current or future energy consumption for heat. It must be considered that summing up the individual potentials to

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[1] No technical potential has been identified in the area of biomass, as no allocation is made in this sector in the various analyses and studies due to the competition for use with other sectors. Further details are provided in the summary and in Section 5.

receive an overall potential is methodologically not expedient, since different supply options are mutually dependent or mutually exclusive.

2. The spatial component is decisive in making the potential accessible in the area of grid-bound energy supply: the potential can only be used if there is adequate proximity to heat sinks. Particularly in this area the potentials often overlap spatially and adding up the individual potentials is not practical. For example, if a heating network is already supplied by thermal waste treatment plants, it is often no longer possible to integrate renewable energies or waste heat which is primarily used in the base load (e.g. solar thermal energy or industrial waste heat), and the potentials cannot be exploited.

3. In addition to the grid-bound potentials, there are also decentralised potentials which cannot all be made accessible due to a quantitatively or qualitatively (spatial, technological, etc.) different consumer structure.

4. Some technologies, such as solar heat generation, require an additional peak load generator or main heat generator. This is partly due to the fact that monovalent coverage of the heat demand can lead to disproportionately higher costs depending on the application (example: seasonal storage of solar heat) and is therefore not economically feasible.

5. Heat pumps can be combined with other supply options. However, there is a risk that the systems may become redundant and thus cause higher costs.

6. The future potential of biomass for heating and cooling supply shows a considerable range of fluctuation. Whereas in Germany, at about 150 TWh/a, about 85 % of renewable heat is currently still provided from biomass, it can be assumed that this share will tend to decline significantly in the future due to the competition with other sectors. Also the absolute biomass potential for heating and cooling supply will tend to decline significantly (see Section 5.3). In this respect, the orientation should tend to be at the lower range of the biomass bandwidths shown in Table 2. A nature conservation consideration in accordance with the method manual of the DBFZ was not carried out.

7. The potentials are related to the efficiency of the building stock or efficiency developments in industry: for example, the possible use of solar energy and heat pumps based on different heat sources increases with higher efficiency of the building stock, even though the energy potential may decrease. Conversely, the potential of a heat-grid-based supply system decreases when building energy consumption falls and the number of connected households does not increase.

8. Since the potentials were determined based on literature research, the framework conditions applied in the studies vary with regard to energy efficiency, future district heating potentials, the types of buildings considered and economic conditions. The corresponding key drivers in determining the potentials are described in the respective sections.

9. It should be noted that the economic potentials identified are strongly dependent on the energy industry and energy policy framework conditions. Both the current framework and the underlying developments presented by the respective authors in the studies have a significant impact on the economic potentials:

- The consideration of a sufficiently high CO_2 price for conventional heat generation increases the costs for the reference technology (mostly gas-based condensing boiler technologies in buildings) and can thus contribute to increasing the corresponding economically viable renewable energy potentials.
- A redesign of taxes and levies on electricity can also lead to higher economic potentials for heat pumps.
- Investment support for renewable district heating increases the investment security of companies and can have a significant impact on the economic potential of renewable district heating.
- Other internal programme cost projections, such as the development of plant costs due to economies of scale, or model-based decision routes influence the results with regard to the economic potentials, but cannot be adapted after publication of the fundamental studies due to the modelling carried out.
- Against this background, it can be assumed in the future on the basis of further developments and findings that the economic potentials may change - both an increase and a reduction cannot be ruled out.

Results and interpretation

In the field of solar energy, decentralised solar thermal and photovoltaic systems as well as large-scale solar thermal systems were analysed. Decentralised as well as large-scale solar thermal systems need to be supported by a peak load or main heat generator. In the case of decentralised solar thermal energy, the potential of conventional solar thermal systems is shown. Systems with extremely large or seasonal storage tanks are not included. The limiting factor in determining the potential is the maximum degree of coverage that solar thermal systems can provide. The technical potential refers to solar useful heat in residential and non-residential buildings and takes their development into account in two scenarios. The economic potential remains significantly below the technical potential. It is strongly influenced by the heat production costs of the required peak load or main heat generator. The economic potential is around three times the current solar thermal expansion. Solar thermal energy can therefore make an important contribution to relieving the burden on other renewable energies, e.g. biomass.

In order to determine the potential of photovoltaics (PV) specifically for heat generation, the potential for photovoltaics on roof surfaces and facades was analysed. Because the boundary conditions are very similar to those for solar thermal energy, the solar thermal potential is also used for heat generation with PV. In addition to heat generation, PV can also provide renewable electricity on buildings.

While the technical potential of large-scale solar thermal energy is in the middle range at 94 TWh for the years 2030 and 2050, the calculated economic potential is lower at 8 to 29 TWh in 2030. However, the technical potential is highly dependent on the underlying area setting. The relatively wide range with regard to the economic potential results from different assumptions regarding the development of the heat network potential and the solar coverage rates (partly due to the use of heat storage systems). Currently, around 40 large-scale solar thermal systems generate around 42 GWh of heat annually, so there is still a very high potential for expansion. Competition with other heat generators (e.g. waste incineration) and land use, as well as the competition with PV for open spaces, can be inhibiting factors in the expansion of central large-scale solar thermal systems. Solar coverage rates in heat networks can be increased in particular by integrating seasonal heat storage facilities (e.g. container, ground basin and aquifer heat storage facilities).

In the field of geothermal energy, the focus was on deep geothermal energy, near-surface geothermal energy in centralised and decentralised use and the potential of mine water. In the case of deep geothermal energy, hydrothermal potentials in Germany for passive and active use using heat pumps were analysed. Depending on the type of integration, the technical potentials amount to 37 to 108 TWh in 2030 and will be reduced to 31 to 88 TWh in 2050 due to the decline in heat demand. However, the economic potentials in heating networks to supply buildings presented are subject to great uncertainty. According to Jochum et al. (2017), the estimate of economic efficiency was derived using a flat-rate, a methodologically simplified limit value for the specific heat production costs for hydrothermal deep geothermal energy of <75 EUR/MWh$_{th}$.

The limiting factor for the use of near-surface geothermal energy by means of decentralised heat pumps in buildings is the ratio of available area for geothermal energy to local heat demand. Especially in dense urban development, decentralised geothermal heat pumps often cannot be used. Away from dense development, the technical potential of near-surface geothermal energy allows the supply of a significant proportion of the building stock, provided the buildings comply with minimum efficiency standards. Central use is limited mainly by the potential for district heating, as the use of central heat pumps based on near-surface geothermal energy is possible at many locations but is restricted by limited space availability or local restrictions on noise emissions. The potential assessment shows technical potentials of up to 650 TWh in 2030 and around 590 TWh in 2050. The economic potentials are to be interpreted cautiously due to the high degree of uncertainty regarding future developments and are reported as up to 170 TWh in 2030 and up to 294 TWh in 2050. More favourable framework conditions in 2050 are already assumed, but the analyses do not make any assumptions about the specific measures and framework conditions.

The thermal potential of mine water for heating and cooling in Germany is low compared to the other potentials (technical potential of 8 TWh in 2030 and 2 TWh in 2050). In the future, the potential will also increase considerably.

Based on the analysis of comprehensive biomass potential studies, the land potential and the potential of cultivated biomass and residual and waste materials identified in the studies were compiled. When analysing the potential of biomass for heating and cooling, competing biomass uses in other sectors must also be taken into account. Within the framework of energy scenario studies, extensive modelling has been carried out based on these restrictions to allocate biomass to the individual consumption sectors and to identify the corresponding economic potentials. The results of the analysis show that the economic potential of biomass in 2030 ranges from 60 to 185 TWh and from 16 to around 187 TWh in 2050. Given the current use of around 150 TWh/a, it is therefore not to be assumed that the total biomass potential for heating and cooling will increase in the future, quite the contrary. In this respect, orientation should tend to be at the lower range of the biomass bandwidths shown in Table 2.

In the field of ambient energy, both centralised and decentralised heat pumps with the heat source ambient energy were analysed and the potential of surface water heat pumps and wastewater heat pumps was presented.

The use of ambient energy using decentralised air heat pumps in buildings has the highest economic potential of the decentralised renewable energies shown for 2050 (up to 85 TWh for 2030 and 242 TWh for 2050). The technical potential is primarily limited by the efficiency of the buildings. If it is possible to reduce the heat requirement to below 90 kWh/m²a over a large area, a broad use of air heat pumps is possible and can also be implemented from an economic point of view.

For central air-source heat pumps in district heating networks, a very high technical potential has been identified: 318 to 531 TWh in 2030 and 425 to 531 TWh in 2050, as it is possible to make the heat source 'air' accessible regardless of location and with few restrictions. Currently, however, the high flow temperatures of the heating networks represent an obstacle to the integration of central air heat pumps. An efficient integration of air-source heat pumps will be facilitated in the future with the transformation towards low network temperatures; then the greatest overall potential can be tapped with outside air as the central heat source.

The potential for the thermal use of surface water in heating networks is in the medium range compared to other heat sources. The difference between technical and economic potentials is relatively small. In Germany the potentials are currently hardly exploited at all. The development of lakes, rivers or the sea using heat pumps is only economically viable if correspondingly large heat sinks are located in the immediate vicinity of the water bodies. The high flow temperatures in existing heating networks, the low level of awareness of the technology and the not uniformly regulated water-legislative conditions also hamper the establishment of surface water development.

The potentials from energy from wastewater in heating networks result from the energetic use of untreated wastewater in the sewage system and from the use of wastewater after the treatment plant. In 2030, the technical potential is up to 46 TWh, in 2050 the potential is reduced to 38 TWh due to the assumed increase in efficiency in the building stock.

When analysing the potentials from waste heat and cold, the potentials from industrial waste heat and cold, those from thermal power plants and waste incineration plants, and those from the tertiary sector are to be analysed. Industrial waste heat and cold can be used for general heat supply as well as for internal use. On the basis of small-scale analyses, the potential for grid-bound use in heating networks was analysed and up to 21 TWh economic potential in 2030 and 15 TWh in 2050 was determined. However, there are uncertainties in the estimation of the long-term available supply potential, which is significantly influenced by economic developments (site selection, plant closures) and technological progress (e.g. process conversions, efficiency measures). Due to data gaps, however, the analyses do not show, for example, the potential from some media flows such as process wastewater, process exhaust air or explicitly "destroyed waste heat" from cooling processes due to a lack of data. Many companies use central cooling systems for production, which have cooling water temperatures of 35-40 °C. The cooling water could be used as a heat source for large heat pumps and thus be made available for heating and cooling. Internal use as an efficiency measure could also further increase the potential.

When determining the potential from thermal waste treatment plants, the biogenic share was deducted in the calculation in order to avoid doubling the potential with that of biomass. Considering the potentials in waste incineration plants, substitute fuel power plants and hazardous waste incineration plants, the fossil fuel-bearing potentials amount to around 16 to 17 TWh in 2030. Analyses up to 2050 cannot be robustly carried out due to major uncertainties in waste management. The potential for waste heat from the tertiary sector can also be used for efficient heating and cooling. Here, however, no comprehensive potential analyses are known in Germany or the EU.

Figure 5 and Figure 6 graphically present the results just discussed for the year 2030 taken from the various literature sources - if available, additional values for the current exploitation of potential are also shown. In Figure 7 and Figure 8 the results are also shown graphically in the form of the bandwidth for the year 2050 taken from the various literature sources.

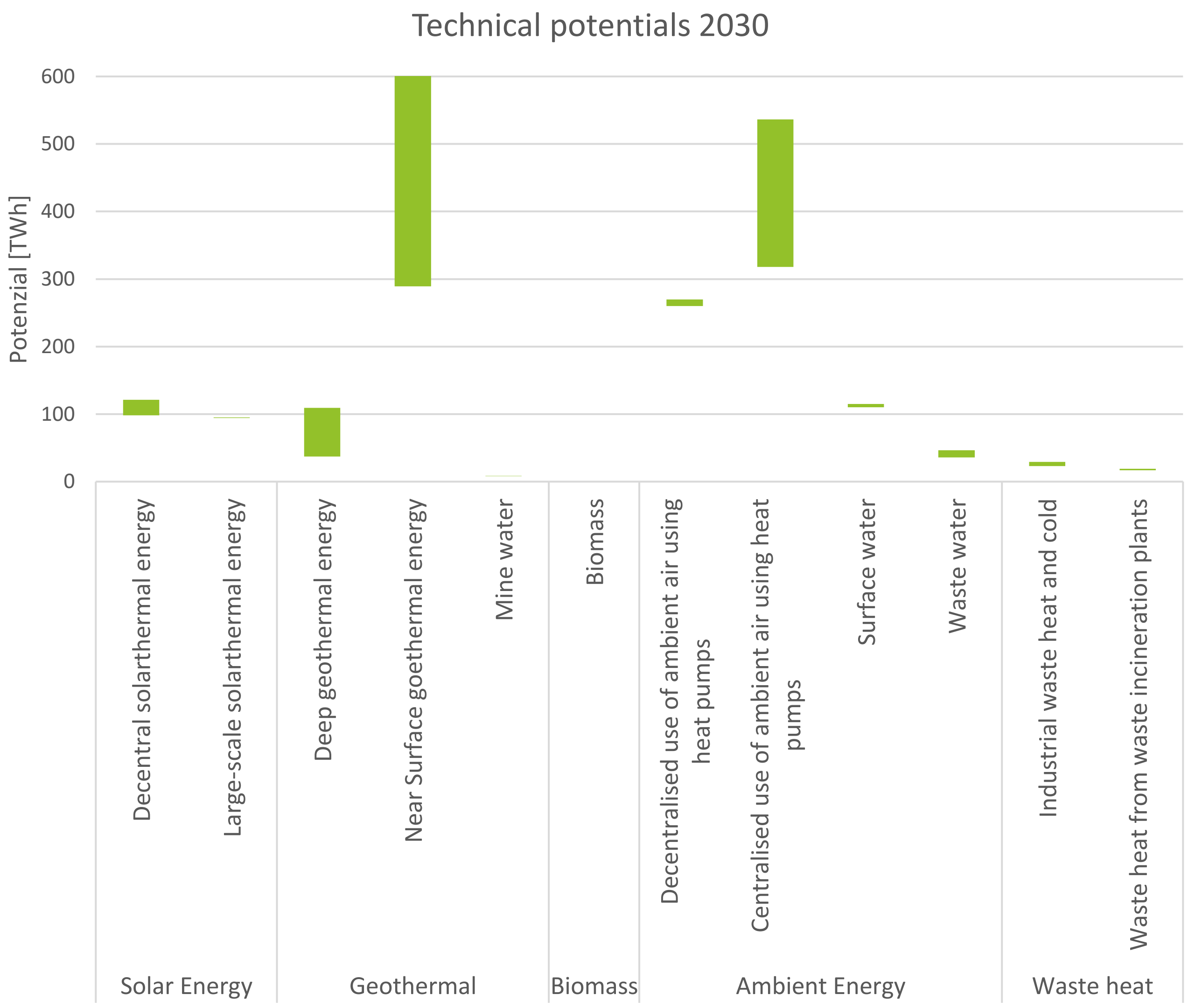

Figure 5: Presentation of technical potentials from renewable energies for heating and cooling in 2030 (Source: own illustration)

The illustration of technical potentials in 2030 in Figure 5 shows their bandwidth in the individual supply options (as a combination of heat source and technology). No technical potential can be identified in the area of biomass, since the various bioenergy sources have different uses in the energy system (electricity, heat, fuel). However, many classic biomass potential studies do not allocate the technical potential to the individual consumption sectors and thus do not identify any bioenergy potential at the final energy level. Further data gaps exist in the case of waste heat from thermal power plants and waste heat from the tertiary sector: while the theoretical potential can be determined for waste heat from thermal power plants, no study has analysed the technical or economic potential. In addition, the power plant park is currently undergoing fundamental restructuring due to the coal phase-out. Nor have individual studies focused on the potential from waste heat from the tertiary sector (including data centres) nationwide.

Figure 6 graphically illustrates the identified economic potentials in 2030. For decentralised solar thermal energy, deep geothermal energy, biomass and waste incineration, the identified potentials are compared with the final energy consumption of the corresponding energy source in 2019 on the basis of AGEE-Stat (2020): It can be seen that in the area of biomass and waste heat from waste incineration a large part of the potential is already being used for heat supply. In the field of decentralised solar thermal energy and deep geothermal energy, a large part of the potential can still be made accessible. Around 15 TWh of the final energy consumption in the heating and cooling sector in 2019 was also covered by near-surface geothermal energy and ambient heat, but this cannot be shown in the diagram due to the different accounting boundaries: If the mentioned current use of near-surface geothermal energy and ambient heat is compared with the potential of these heat sources, it becomes clear that there is still great unused potential here.

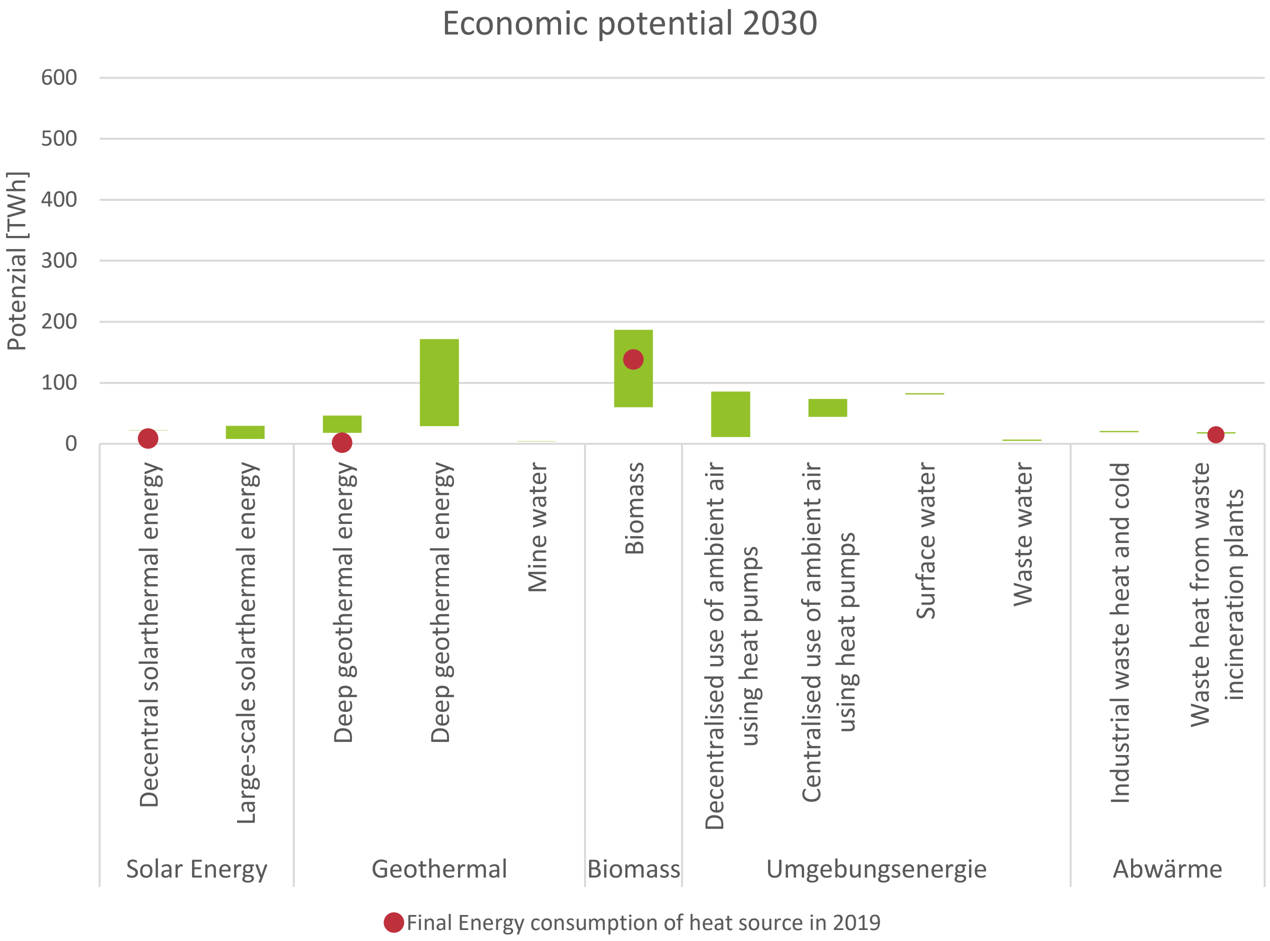

Figure 6: Presentation of the economic potential of renewable energies for heating and cooling in 2030 (Source: Own Illustration; final energy consumption from AGEE-Stat (2020))

The presentation of technical potentials in 2050 in Figure 7 shows the range of potentials of the individual supply options (as a combination of heat source and technology) analogous to the presentation for the year 2030.

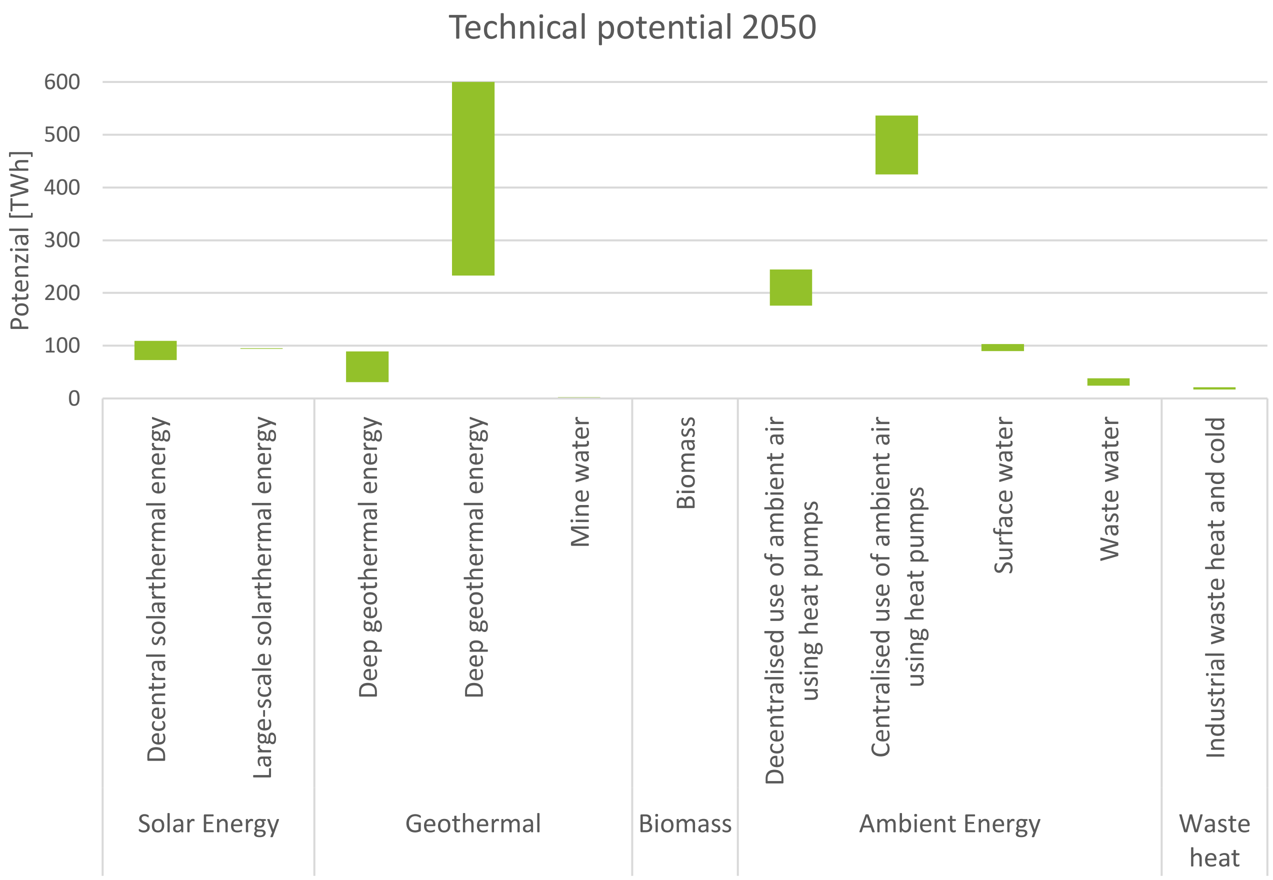

Figure 7: Presentation of the technical potential of renewable energies for heating and cooling in 2050 (Source: own illustration)

Figure 8 graphically illustrates the identified economic potentials in 2050. For decentralised solar thermal energy, deep geothermal energy, biomass and waste incineration, the identified potentials are again compared with the final energy consumption of the corresponding energy source in 2019 based on AGEE-Stat (2020). In general, larger bandwidths are apparent in 2050 than in 2030.

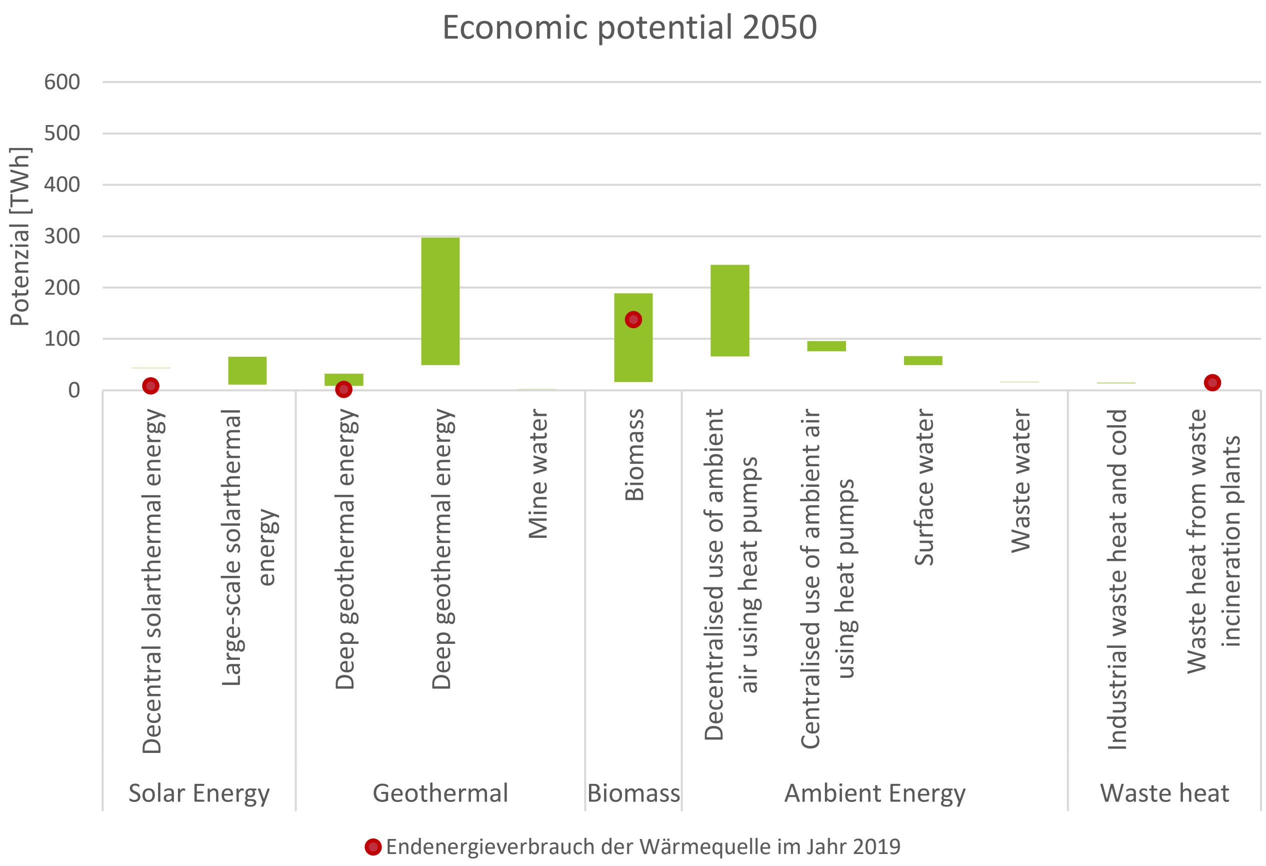

Figure 8: Illustration of the economic potential of renewable energies for heating and cooling in 2050 (Source: Own Illustration; final energy consumption from AGEE-Stat (2020))

3 Introduction and definition of terms

The Commission imposes the following requirement in Article 15(7) of the Renewable Energy Directive (RED II):

‘Member States shall carry out an assessment of their potential of energy from renewable sources and of the use of waste heat and cold in the heating and cooling sector. That assessment shall, where appropriate, include spatial analysis of areas suitable for low-ecological-risk deployment and the potential for small-scale household projects and shall be included in the second comprehensive assessment required pursuant to Article 14(1) of Directive 2012/27/EU for the first time by 31 December 2020 and in the subsequent updates of the comprehensive assessments.’

This report assesses the technical and economic demand potential in the field of energy from renewable sources and the use of waste heat and cold in the heating and cooling sector, as well as the identification of renewable potentials for the status quo and for the years 2030 and 2050.

This will be done in close coordination with the comprehensive assessment for the promotion of efficiency in heating and cooling supply provided for in Article 14 of Directive 2012/27/EU, and within the framework of two parallel projects implemented by the German Environment Agency [Umweltbundesamt, UBA] and the Federal Energy Efficiency Centre [Bundesstelle für Energieeffizienz, BfEE].

3.1 Definitions

3.1.1 Sources of heat according to RED II

RED II contains the following definitions that are relevant for the purposes of the analysis:

- ‘energy from renewable sources’ or ‘renewable energy’ means energy from renewable non-fossil sources, namely wind, **solar (solar thermal and solar photovoltaic) and geothermal energy, ambient energy,** tide, wave and other ocean energy, hydropower, **biomass, landfill gas, sewage treatment plant gas, and biogas;**
- ‘waste heat and cold’ means unavoidable heat or cold generated as by-product in industrial or power generation installations, or in the tertiary sector, which would be dissipated unused in air or water without access to a district heating or cooling system, where a cogeneration process has been used or will be used or where cogeneration is not feasible;
- ‘geothermal energy’ means energy stored in the form of heat beneath the surface of solid earth;
- ‘ambient energy’ means naturally occurring thermal energy and energy accumulated in the environment with constrained boundaries, which can be stored in the ambient air, excluding in exhaust air, or in surface or sewage water.

The definition of ambient energy in RED II differs in scope to the definition that applies at national level in Germany, which was provided by the German Environment Agency. The definition adopted by the German Federal Government in the Buildings Energy Act is essentially the same as the definition in RED II (Deutscher Bundestag, 2020).

Definition of environmental heat in Germany according to the German Environment Agency

Ambient heat includes both environmental heat and near-surface geothermal energy. The former includes heat extracted and made technically usable from atmospheric layers close to the ground ('aerothermal environmental heat') or surface waters ('hydrothermal environmental heat') (by way of analogy to the Renewable Energies Heating Act [Erneuerbare-Energien-Wärmegesetz, EEWärmeG]). Near-surface geothermal energy refers to the heat stored in the near-surface layer of the soil, down to a depth of 400 m ('geothermal environmental heat'). This also includes heat in ground water.

Definition of environmental heat in Germany in accordance with the Buildings Energy Act

According to the Act, 'environmental heat' is heat or cold extracted and made technically usable from the air, from the water or from flows of waste water originating from technical processes and structural works, with the exception of the heat extracted from flows of exhaust air originating from technical processes and structural works.

The potential analyses in this study take into account renewable energies that are used directly or in combination with heat pumps for heating and cooling supply (solar energy, geothermal energy, biomass, landfill gas, sewage gas and biogas, ambient energy and waste heat and cold). Since the data regarding the shares accounted for by the individual energy sources have been disaggregated, the above difference in definition is irrelevant, *inter alia* as regards comparability with statistical data collected in connection with other reporting obligations (national or international). The use of renewable electricity for heating or cooling supply without heat pumps is examined in a background note on power-to-heat systems. **The RED II definition will be used for the purposes of this report.**

3.1.2 Definition of potential

The underlying studies and analyses use different definitions of the term 'potential' depending on heat source; these are broken down below. Figure 9 shows a breakdown of the definitions of the term 'potential' based on Kaltschmitt et al. (2003). Technical potential can be calculated as a sub-quantity on the basis of theoretical potential, and either the economic potential or the accessible potential can subsequently be identified.

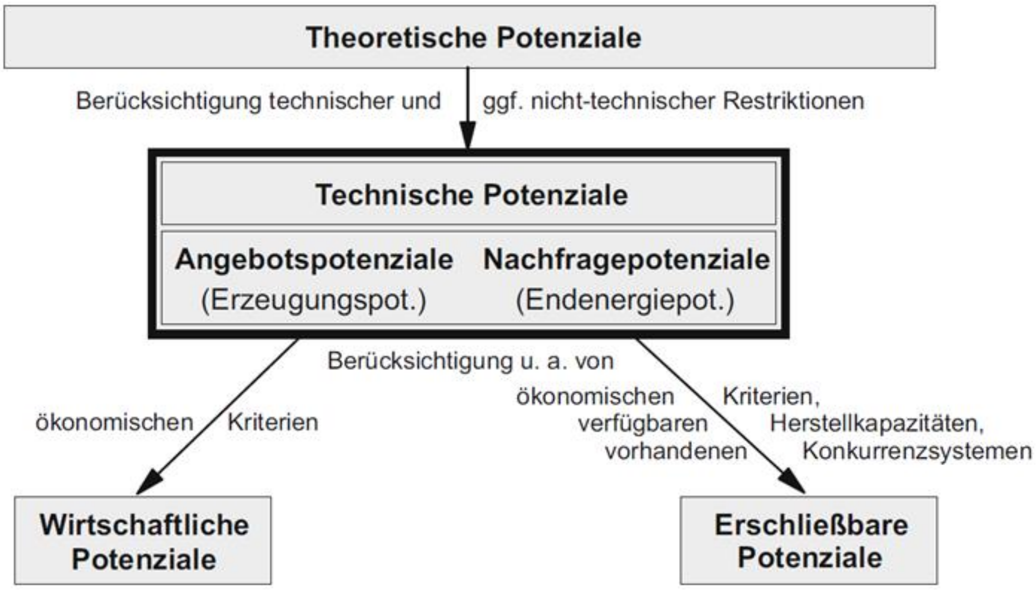

Figure 9: Breakdown of the definitions of the term ‘potential’ based on Kaltschmitt et. al (2003)

Theoretische Potenziale	Theoretical potentials
Berücksichtigung technischer und ggf. nicht-technischer Restriktionen	Consideration of technical and (where applicable) non-technical restrictions
Technische Potenziale	Technical potentials
Angebotspotenziale (Erzeugungspot.)	Supply potentials (generation potentials)
Nachfragepotenziale (Endenergiepot.)	Demand potentials (final energy potentials)
Berücksichtigung u. a. von	Consideration of factors including
ökonomischen Kriterien	economic criteria
ökonomischen Kriterien	economic criteria
verfügbaren Herstellkapazitäten	available manufacturing capacities
vorhandenen Konkurrenzsystemen	existing competing systems
Wirtschafliche Potenziale	Economic potentials
Erschließbare Potenziale	Accessible potentials

According to Kaltschmitt et al. (2003), the **theoretical potential** is equivalent to the supply of energy that can physically be used over a temporally and geographically fixed observation period. This includes total renewable biomass per year, for example, or the amount of waste heat that can theoretically be delivered at industrial locations, assuming a constant minimum heat sink temperature and ignoring technical restrictions. Technical, economic and other obstacles mean that it is impossible to access the theoretical potential in full, however, and it is accordingly least relevant when analysing potential.

The term ‘**technical potential**’ refers to the share of theoretical potential that can be accessed using known technologies and supply procedures. This definition takes account of any applicable restrictions, for example in the case of biomass used for the supply of food. Particularly in systems that involve grid-bound heating supply, it is useful to differentiate between **supply and demand potential** for the purpose of categorising potentials; supply potentials focus on technical accessibility, whereas the determination of demand potentials also considers use in potential heat sinks. For example, not all technical geothermal energy potentials are accessible, because network losses incurred as a result of distance from potential heat sinks make access difficult or impossible. Analysis of demand potentials also explicitly incorporates efficiency measures in the building stock that affect heat demand; technical demand potentials may drop in absolute terms in better insulated buildings owing to a reduction in the useful heat demand on the heat sinks. The share of total useful energy demand that can be supplied by the relevant renewable sources is correspondingly higher, however.

As a final step, economic criteria such as investment costs for making the potential accessible and the costs of operation and maintenance are taken into account. **Economic potentials** therefore also depend on the framework conditions in place as regards the energy industry and energy policy, since the resulting heat production costs must always be viewed in relation to the reference technologies. Higher costs associated with the pricing of fossil-based energies (e.g. CO_2 prices) or low investment costs for making renewable energies accessible (e.g. funding schemes) may have a significant impact on economic potentials. The economic potentials therefore respond much more sensitively to variations in the individual parameters. Another factor that has a significant impact relates to whether the potentials are examined from a business perspective or an economic perspective; whereas an analysis carried out from a business perspective typically takes into account the taxes, levies and funding schemes that currently apply[1], these external costs are ignored when carrying out an analysis from an economic perspective.

What is more, **accessible potentials** (which are equivalent to the smallest sub-quantity) ignore non-economic barriers such as information deficits on the part of potential heat customers, acceptance problems affecting the accessibility of various heat sources or competition between the individual heat sources on the market.

The literature typically specifies different potentials depending on the heat source or supply option to be analysed. In the case of biomass, for example, the technical potentials are typically analysed but the available resources are not allocated to the various options for use, and no attempt is made to break down the competition that exists between the different uses. In the case of geothermal energy, the analysis of potentials generally focuses on demand potentials, since the proximity of a heat source and a heat sink is a crucial factor that determines whether use is possible. When assessing the possible use of industrial waste heat, technical potential – the external grid-bound quantity of waste heat that can be delivered, taking into account ‘real’ heat sinks and waste heat temperatures and the corresponding technologies to be used – is once again the determining factor. In the field of solar thermal energy, many studies specify only a joint technical and economic potential, since it is often a difficult task to distinguish clearly between economic restrictions (e.g. the costs of making potentials accessible as a result of large distances between heat sources and heat sinks) and technical restrictions.

In so far as possible, this report harmonises the different underlying data types and translates them into technical and economic demand potentials for the target years (2030 and 2050) that can be compared against each other. Where specified in official energy statistics, the current utilisation of potential is stated for contextualisation purposes. The figures are drawn from the regular publications by the Working Group on Renewable Energy Statistics (AGEE-Stat) (AGEE-Stat, 2020).

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[1] Or includes them in projections for the purpose of analysing future potentials.

3.2 Situation in Germany

In 2018, final energy consumption for heating and cooling was approximately 1 300 TWh. Consumption of process heat in industry accounts for a large proportion of this figure (around 496 TWh), exceeding space heating in residential buildings (around 427 TWh) and space heating in the services sector (around 168 TWh). Ambient cooling and process cooling play a subordinate role, accounting for around 35 TWh (which corresponds to 2.6% of total final energy consumption in Germany).

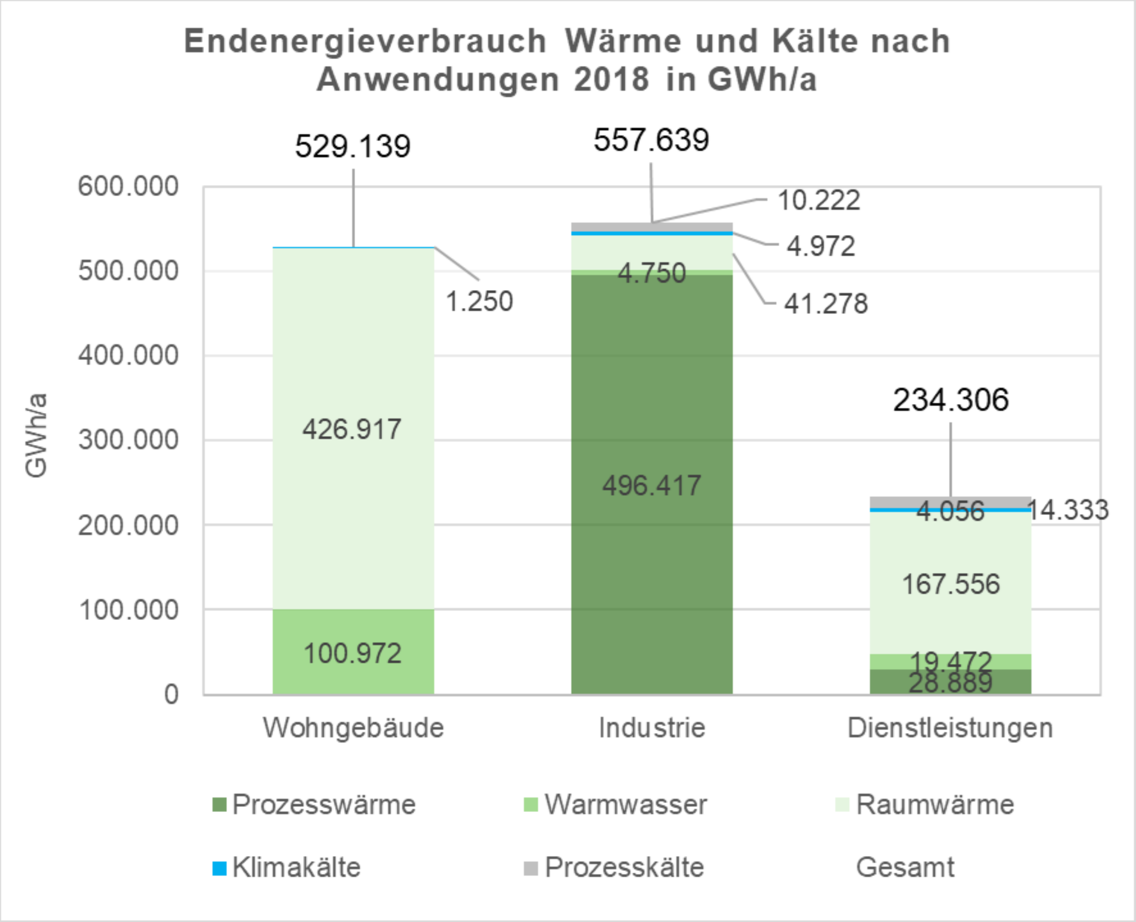

Figure 10: Final energy consumption for heating and cooling supply in Germany (source: Steinbach et al. (2020))

Endenergieverbrauch Wärme und Kälte nach Anwendungen 2018 in GWh/a	Final energy consumption for heating and cooling in 2018, broken down by application, in GWh/a
GWh/a	GWh/a
Wohngebäude	Residential buildings
Industrie	Industry
Dienstleistungen	Services
Prozesswärme	Process heat
Warmwasser	Hot water
Raumwärme	Space heating
Klimakälte	Ambient cooling
Prozesskälte	Process cooling
Gesamt	Total

3.3 Procedure for analysing potential

The renewable potentials for heating and cooling supply in Germany are analysed on the basis of a literature review. The procedure is carried out for the individual heat sources defined in Article 2(1) sentence 1 and sentence 9 of RED II, with the exception of tide, wave and other ocean energy and hydropower[1]. Where relevant, further differentiation is carried out on the basis of technologies or heat sources, and a final summary is provided for each of the heat sources. Further differentiation by technologies is referred to below as 'supply options'.

Where possible, both the technical and the economic demand potentials for 2030 and 2050 are presented in each case. The potentials should not be regarded as additive; instead, they should be interpreted independently of one another. The following sections categorise the different potentials.

This assessment draws on the statistical definition of the potential analyses that have already been carried out (some of which are small-scale and highly detailed). In scenarios involving the deployment of heat pumps, the use of electricity and renewable sources in the heating and cooling sector is shown jointly, which means that gross values including operating power are presented.

The potentials are analysed on the basis of literature research, which means that they cannot be fully harmonised across all the energy sources with reference to different parameters (e.g. thermal standards of the building stock) and assumptions regarding future developments (e.g. changes in energy prices or assumptions about the EU-ETS or CO_2 pricing).

The following parameters are relevant in the analysis of potential:

- changes in the efficiency of the building stock: depending on the technology used, the efficiency of the building stock can have a significant influence on potentials, albeit to a differing extent for the various supply options; although efficient buildings have a positive impact on potential in the sense of opportunities for installing heat pumps, the absolute potential of deep geothermal energy drops in renovated buildings while the relative share rises,
- future role of heating networks: the potentials of supply options that are particularly suitable for use in grid-bound heating infrastructures depend to a large extent on the future role of district heating networks and their share of the heating supplied to the building stock,
- useful and final energy accounting: different studies analyse potential on the basis of either useful or final energy,
- changes in political framework conditions, in particular as regards the economic feasibility of the various options (e.g. CO_2 pricing).

The respective parameters are identified and highlighted in the analysis contained in each individual section. It should furthermore be noted that the simple addition of potentials – particularly in the case of potentials used in grid-bound infrastructures – is often possible to only a limited extent.

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[1] These sources are excluded from the analysis since it is assumed that – in accordance with Germany's targets – the share of renewable energies in the electricity mix will increase up to 65% by 2030. Interdependencies with the heating and cooling supply are examined through an analysis of the use of heat pumps and a background note on power-to-heat.

Fundamental uncertainty exists over calculations of demand for cooling production and renewable energy potentials in the production of cooling. Calculations of final energy demand for space heating and hot water reflect real consumption with a certain margin of error, but real final energy demand for ambient cooling is almost impossible to quantify. Cooling is a less established technology than heating in Germany. Perceptions of heat and responses to it vary greatly from person to person. The cooling technologies that are used also differ enormously in terms of energy inputs and outputs. They range from manual night-time ventilation and temperature control methods based on heat pumps through to high-performance air conditioning systems.

Final energy consumption for ambient cooling was around 11 TWh in 2017. This corresponds to 1.3% of the consumption for space heating and hot water (BMWi 2019). The demand potential for ambient cooling may significantly exceed this figure, however. There are no known findings in this area. The available options for using different renewable sources in the cooling sector are presented in the corresponding sections.

Findings concerning renewable potentials in industry are also limited, and derive from a small number of studies. If information is available for an individual heat source (e.g. large-scale solar thermal energy), the corresponding potentials are specified. According to the models produced in connection with the Climate Action Programme 2030 (Bundesministerium fuer Umwelt Naturschutz und nukleare Sicherheit (BMU), 2019) and the National Energy and Climate Plan (NECP) (Bundesministerium für Wirtschaft und Energie, 2020), the share of industrial heating and cooling demand (not including district heating and electricity) covered by renewable energies will be 7% by 2030 and 22% by 2050. The share of district heating will increase from 10% in 2020 to 12% in 2030 and 14% in 2050. By way of contrast, the share of useful energy consumption for space heating and hot water supply in residential buildings covered by renewable energies is to increase to 13% by 2030 and 41% by 2050.

The demand for process electricity in industry (137 PJ in 2012 (Bundesministerium für Wirtschaft und Energie (BMWi), 2018)) will gradually switch over to renewable energies as a result of the expansion of renewable energies in the electricity sector.

4 Potential analysis of solar energy

The following use cases are examined separately for the purpose of analysing potentials in the solar energy sector:

- decentralised use in the building stock on the basis of solar thermal and photovoltaic energy (see Section 4.1),
- large-scale solar thermal energy for the grid-bound supply of heat or the production of process heat (see Section 4.2).

4.1 Decentralised solar thermal energy and photovoltaics

As a basic principle, two different procedures exist for the active use of solar radiation for space heating and the heating of domestic hot water: solar thermal systems and photovoltaic (PV) systems in combination with an electric heat generator. Passive use of solar radiation by means of heat gains from opaque and transparent components does not qualify as a renewable energy within the meaning of RED. They are included on the balance sheet when energy demand is calculated. Systems for the decentralised supply of space heating and domestic hot water are discussed below.

4.1.1 Introduction

Solar thermal systems for space heating and process water are typically operated at a temperature of up to 85 °C in order to avoid overheating the storage tank. Owing to seasonal fluctuations in availability, solar thermal systems are generally operated in bivalent mode with other heat sources. As a basic principle, they are therefore suitable as a back-up for heat generators in private households, the commerce, trade and services sector and industry. This also applies analogously to the production of heat using PV systems.

At low temperatures, water is used as a storage medium. The period of storage is a few days, depending on the size of the storage tank and the demand for heat. For large seasonal storage tanks with an approximate size of 20-200 m³, the period of storage is several months. Systems of this kind are already available on the market, but only in the form of customised solutions. Although long storage periods are also possible if heat is stored in ice storage units, in the ground or in aquifers, the number of systems of this kind currently in operation is once again small.
Conventional heat storage tanks are typically used in the case of PV systems for the production of heat; PV electricity is converted into heat in these installations using electric heating elements. Alternatively, PV systems can also be combined with heat pumps, which results in significantly more efficient use of the electricity. The manner in which the heat is produced is not further investigated in the remainder of this report; instead, the focus is on the supply potential of the PV systems. By way of contrast to solar thermal systems, the solar yield is not limited by the size of the storage tank. Electricity generated in excess of the storage capacity is used for other household appliances or fed into the electricity grid.

As a basic principle, solar thermal systems must be operated in combination with a second heat generator, since demand cannot be covered solely by the heat produced during the heating period (this does not include systems based on seasonal storage, since they are not widely available on the market). The nature of the second heat generator has a technical and economic impact on solar potentials. The heat source can be regenerated using a combination of heat pumps and solar thermal energy, for example. This involves discharging solar-generated heat into the ground (into probes or geothermal collectors) or into an ice storage unit. Both can store large quantities of heat at a low temperature. Solar output is increased through the high storage capacity and large temperature difference. Unwanted boiling in the collector circuit is avoided. Higher heat source temperatures may significantly increase the coefficients of performance of the heat pumps. On the one hand, technical heat pump potential is increased by higher coefficients of performance; on the other hand, solar heat can also be used as a gateway to heat pumps, and may be the only way to render their use feasible in certain buildings (see the discussion of near-surface geothermal energy in Section 7.2).

Designs that combine solar thermal energy with heat generators which have high fuel costs are advantageous from an economic perspective. Combinations with heat generators which have high capital costs and which are paid off through low fuel costs are less favourable, however, since the technologies encroach on each other's territories, economically speaking.

4.1.2 Total heating and cooling potential and classification

This section opens with a discussion of the technical and economic potentials of decentralised solar thermal energy systems in Germany, drawing on various studies. Table 3 provides an overview of the ranges of potentials that can be observed in the literature. Details of the individual data sources are provided below as a basis for describing the assumptions underlying these sources that lead to the respective findings regarding potentials.

Table 3: Overview of results of potential analysis for decentralised solar thermal energy and PV heat

Energy source (TWh/a)	Technical potential		Economic potential	
	2030	2050	2030	2050
Solar – decentralised solar thermal energy	98-120	73-108	22	43

Jochum et al. (2017) calculated the potential of decentralised solar thermal energy for single-family dwellings and multi-family dwellings, as well as for selected non-residential building types (accommodation, sports venues, hospitals). This study was based on the results published by **Roger Corradini (2013)**, who analysed the potential of decentralised solar thermal energy for single-family dwellings on the basis of building stock data that were regionally differentiated at the level of municipalities and classified according to type. Since changes in building efficiency have a major impact on future potentials, the potentials for two different heat consumption scenarios were calculated: 'Trend' and 'Ambitious climate protection'. These scenarios illustrate the maximum anticipated range of consumption. In the 'Trend' scenario, useful heat consumption reduces by 13% up to 2030 and by 33% up to 2050. In the 'Ambitious climate protection' scenario, it drops by 32% up to 2030 and by 63% up to 2050. The potentials were calculated on the basis of solar thermal simulations that take into account the solar coverage rate depending on useful heat consumption and roof shape. The simulation outcomes were extrapolated to the total stock on the basis of a buildings model. The **technical potential of decentralised solar thermal energy** in the 'Trend' scenario is 120 TWh for **2030**, dropping to 108 TWh by 2050. In the 'Ambitious climate protection' scenario, it is 98 TWh in 2030 and 73 TWh in 2050. It follows that the technical potentials decrease in absolute terms by 2050 compared to 2030 (since the reduction in useful heat consumption exceeds the possibilities for more efficient use involving lower flow temperatures in buildings), but increase in relative terms as a share of overall consumption.

In a study by the Fraunhofer Institute for Solar Energy Systems [Fraunhofer-Institut für Solare Energiesysteme, Fraunhofer ISE], **Sterchele et al. (2020)** investigated how a climate-neutral energy system in Germany might be implemented in future, highlighting various factors such as the economic potentials of solar thermal energy. The accounting boundaries of the investigation encompass the electricity, heat, industry and transport sectors. The framework conditions include an assumed reduction in greenhouse gases of 95% compared to 1990. The analysis furthermore provides for the optimised use of resources and potentials within the accounting boundaries. A model that performs an economic optimisation of the energy supply is used to simulate the supply of energy up until 2050, taking into account the current building stock situation, the lifetimes of the components and technology-specific assumptions regarding costs, operation and potential. As a result, the study shows that the use of solar thermal energy – on the basis of the assumptions made – is economically feasible both for heating buildings and domestic hot water and for the supply of industrial heat at low and medium temperatures. The energy prices of conventional technologies (natural gas and oil) are set to remain constant until 2050. In the case of solar thermal collectors, a decreasing trend is assumed for investment costs (from EUR 550/m^2 in 2020 to EUR 310/m^2 in 2050). Detailed assumptions about costs and energy quantities are provided in the annex to the study by Sterchele et al. (2020). The results of the economic optimisation in the reference scenario for the buildings sector suggest **economic potentials for decentralised solar thermal energy** of 18 TWh in **2030** and 33 TWh in 2050. In the case of industrial applications, the economic potentials of solar thermal energy are 4 TWh in 2030 and 10 TWh in 2050. At the same time, it must be remembered that the economic potentials are calculated for specific framework conditions. If the framework conditions change, the potentials may differ from those stated.

Several studies have investigated the **potentials for the generation of electricity using PV systems**. They do not examine how the generated electricity is used, however, which means that an explicit analysis of PV potential for the production of heat is not available. Free-standing PV systems are not included below, since they do not qualify as renewable energy in the context of the buildings sector. As a basic principle, renewable electricity contributes to the decarbonisation of the buildings sector; at the same time, however, it does not qualify as renewable energy for the purpose of heat production within the meaning of RED II.

The investigation carried out by **Peters et al. (2015)** calculated PV potential on the basis of roof surface potentials and average levels of module efficiency. Non-residential buildings are incorporated on the basis of a standard factor. The **supply potential** of roof-mounted PV systems in **2011** is specified as 149 GW$_p$ or 141 TWh. If solar thermal energy were prioritised, it would be necessary to reserve 40% of roof surface for this purpose. The PV potential would then drop to 84 TWh.

A **study by Lödl et al. (2010)** uses building sizes in different residential categories and regions in Bavaria as a basis for calculating the maximum PV system output. The ratio of system output to building footprint in Bavaria was extrapolated to Germany as a whole by Lödl et al. using the building footprint statistics of the federal states. A flat-rate deduction of 34% of roof surface was applied for the purpose of taking into account the possible use of solar thermal systems. This results in a supply potential of roof-based PV systems of 161 GW$_p$. The potential of the supplied energy quantity is not specified.

Karoline Fath (2017) calculates significantly higher PV potentials in her dissertation, which was completed at the Karlsruhe Institute of Technology (KIT). The potentials were calculated at building and housing density level on the basis of thermal radiation simulations with high temporal and spatial resolution. The potentials were calculated for five housing density categories, and broken down into residential and non-residential buildings. The study is based on the building perimeters contained in geoinformation systems for Baden-Württemberg, and therefore also includes unheated buildings. Roof and façade surfaces were calculated using standard factors on the basis of the perimeters.

Levels of shade and reflections were taken into account as influencing factors in 3D thermal radiation simulations, which meant that the potential of **PV façade systems** could also be calculated. By way of contrast to most other investigations of potential, standard deductions were not applied for the purpose of taking into account structural restrictions or solar thermal energy. The results for Baden-Württemberg were extrapolated to Germany as a whole using statistical methods.

According to Fath (2017), the **technical potential** for decentralised PV systems on roofs and façades is 2 923 TWh for **2015** and up to 6 279 TWh for **2050**. The **economic potential** is 2 482 TWh for 2015 and up to 4 210 TWh for **2050**. PV systems on residential buildings account for 27% of the overall potential, while PV systems in purely commercial and industrial areas account for 40% of the potential. This high percentage plays a key role in the significant differences that can be observed between this and previous studies, but also results from the use of building perimeters, which allows the building stock to be captured to the fullest possible extent.

Since no allocation to heating and cooling supply is carried out, however, the potential is not further considered in the remainder of this report.

4.2 Large-scale solar thermal energy

4.2.1 Introduction

As centralised production units, large-scale solar thermal systems typically feed heat into local or district heating networks in the form of heated water. The systems provide a centralised supply of grid-bound heat produced in solar collectors to districts, residential areas, villages or urban neighbourhoods. Collector panels are installed in open spaces or integrated into building roofs. The end customers of the solar heat are private households connected to the solar heating network and consumers in various sectors (the commerce, trade and services sector and the industrial sector). Solar district heating can be used to cover the applications ‘space heating’ and ‘domestic hot water’. It is also possible to use large-scale solar thermal energy to supply process heat. In Germany, this takes place primarily at temperatures in a range between 20 °C and 130 °C (Ritter et al. 2017). In the case of solar thermal energy, the widespread availability of solar radiation means that the theoretical potential available in Germany is in principle very large. The technical and economic use of centralised solar thermal energy is limited by the following two central factors:

- heating network potential, and
- solar coverage rate within the heating networks.

In order to integrate centralised solar thermal energy into the heating supply, the solar-produced heat must be transported and distributed to the customers. This is achieved by means of heating networks. Changes in the quantity of district heating as a proportion of the overall heating supply and the absolute quantity of district heating supplied over the period up to 2050 will therefore affect the large-scale solar thermal potentials that are available for integration. Heating networks are particularly useful in areas with high heating densities. This applies to urban and densely populated areas, but the availability of open spaces for the installation of solar collectors tends to be limited in such areas.

The solar coverage rate designates the annual share of heat in a district heating network that is supplied by solar thermal systems. It depends on the size of the collector array, the capacity of the heat storage unit and the pattern of consumption. The seasonal nature of availability means that solar thermal systems primarily cover heat demand during the summer months (e.g. for the purpose of heating domestic hot water). The solar coverage rate can be increased by means of a seasonal heat storage unit. In the absence of seasonal heat storage units, the solar coverage rate is approximately 15-20%; with seasonal heat storage units, a solar coverage rate of over 50% can be achieved.

Systems which are in competition with large-scale solar thermal energy include all generators that are capable of bearing a constant load and that are used for district heating purposes, such as waste incineration plants or industrial waste heat. It would be difficult for large-scale solar thermal generation units to compete with these options without seasonal storage units. The seasonality of generation technologies that use ambient heat, such as air-source heat pumps or surface water-source heat pumps, means that they are also competing systems. To a limited extent, free-standing PV systems that generate electricity also compete for the same areas of land.

The solar thermal system Hirtenwiesen 2 in Crailsheim (Baden-Württemberg), which covers an area of 5 000 m², is a best practice example. This large-scale solar thermal system is installed on a noise protection barrier and on roofs (see Figure 11) and feeds into the area's local district heating network. Seasonal heat storage units are integrated in the form of a hot water tank and as geothermal probe heat storage units, resulting in a solar coverage rate for the system of 50%. A land-use concept incorporates the system into the location's landscape and ecology. Extensive meadow areas increase biodiversity, and recreational meadows improve quality of life.

Figure 11: The 'solar wall' that forms part of the Hirtenwiesen 2 system in Crailsheim. Courtesy of: Hamburg Institute.

4.2.2 Total heating and cooling potential and classification

This section opens with a description of the technical and economic potentials of large-scale solar thermal systems in Germany, drawing on various studies. Table 4 provides an overview of the range of potentials specified in the literature. Details of the individual data sources are provided below as a basis for describing the assumptions underlying these sources that lead to the respective findings regarding potentials. The section ends with a background note on the production of solar cooling. To a large extent, the cooling potentials depend on future changes in demand for cooling.

Table 4: Overview of results of potential analysis for centralised solar thermal energy

Energy source (TWh/a)	Technical potential		Economic potential	
	2030	2050	2030	2050
Solar – solar thermal energy, centralised of which:	94	94	4-25	11-65
District heating	78	78	4-25	1-56
Process heat	16	16	4	10

Results from the ongoing **comprehensive assessment project by the German Environment Agency 'Analysis of economic potential for an efficient supply of heating and cooling – contribution to the reporting obligation under Article 14, Annex VIII to the Energy Efficiency Directive' (Ortner et al., ongoing)** are used to present the technical potential. The approach followed in this project involves identifying open spaces that could possibly accommodate large systems in suitable heating network regions. Potentials are calculated on the basis of the geographical overlaps between suitable open spaces[1] for solar thermal systems and the possible heating network regions[2] that have been identified, with a minimum distance of 1 km between these regions. The gross surface area identified as being available for solar thermal collectors in suitable heating demand regions is approximately 190 km² in total (around 0.05% of Germany's total surface area). The technical demand potential identified for 2030 and 2050 is 77.8 TWh/a.

The study **'The potential of solar process heat in Germany' by the University of Kassel (Lauterbach et al. 2011)** is one of several studies that calculate the potential of solar thermal energy to cover industrial process heat. The study investigates the demand for industrial heat in processes and identifies the temperature ranges that can be covered by solar thermal energy. The technical potential (including available roof surfaces and efficiency measures) for the base year 2010 is calculated as around 16 TWh.

When determining economic potentials in the field of large-scale solar thermal energy, additional assumptions must be made regarding changes in district heating infrastructures and solar coverage rates within the district heating systems. Table 5 outlines the assumptions made in the three cited studies that calculate these potentials.

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[1] The CORINE Land Cover datasets from the Copernicus Land Monitoring Service form the basis for the surface area calculations.

[2] Regions with a minimum heat density of 15 GWh/km² and annual heat sales of 15 GWh are defined as possible heating network regions.

The studies make assumptions about the areas of land available for free-standing solar thermal systems; this involves identifying contiguous areas (e.g. agricultural land) directly adjacent to suitable heat sinks. It is possible that the technical and economic potentials determined in this way are somewhat higher than the convertable potentials, since the identified areas may not be available to the presumed extent (land problem, also discussed by Sandrock et al. 2019). Reasons include areas that are unsuitable as a result of nature conservation criteria, or drinking water protection areas.

Table 5: Economic potentials for centralised solar thermal energy with underlying assumptions concerning shares of district heating and solar coverage rates in the district heating networks. (Own illustration on the basis of Jochum et al (2017), Gerhardt et al. (2019) and Gerbert et al. (2018))

	District heating as a share of the heat supply		**Solar coverage rate within the district heating networks**	**Potential [TWh/a]**	
	2030	**2050**		**2030**	**2050**
Jochum et al. 2017	'Trend' scenario, moderate renovation, residential buildings:		small share of seasonal storage reservoirs: **Solar coverage rate 20%** (can be increased to 30%)	15.4	6.5
	29%	**24%**			
	'Ambitious renovation' scenario, residential buildings:			7.7	1.1
	24%	**25%**			
Gerhardt et al. 2019	'Trend' scenario, moderate renovation: **44% 2030** (all buildings)		Urban areas, only daily storage reservoirs: **Solar coverage rate 15% (2030), 20% (2050)**; rural areas with seasonal storage reservoirs: **Solar coverage rate 40% (2030), 45% (2050)**	25	55.5
	'Ambitious renovation' scenario: **35% 2030** (all buildings)			25	25
Gerbert et al. 2018	'Reference' scenario, low renovation:		Stringent restrictions for solar thermal energy on the basis of a time lag in supply/demand of solar heat and competition for land with PV; low solar coverage rate; model results: - 80% scenario: Solar coverage rate 5% (2030) and 14% (2050) - 95% scenario: Solar coverage rate 6% (2030) and 12% (2050)	4	8
	12%	**14%**			
	Scenario 80%, medium renovation:			8	19
	15%	**21%**			
	Scenario 95%, high renovation:			9	20
	16%	**26%**			

Gerhardt et al. (2019) specify the economic potential of free-standing solar thermal systems in 2030 as 25 TWh/a for both scenarios, and in 2050 as 25 TWh/a again (final energy demand of 362 TWh/a for the ‘Ambitious’ scenario) and 55.5 TWh/a (final energy demand of 525 TWh/a for the ‘Trend’ scenario). It is particularly noteworthy that the economic potentials more than double between 2030 and 2050 for the moderate scenario outlined in Gerhardt et al. (2019). In the case of the ‘Ambitious’ scenario described by Gerhardt et al. (2019), however, the economic potentials stagnate owing to an extreme reduction in final energy consumption. A distinction is made between urban and rural heating networks when the production costs for solar district or local heating are calculated. The costs for urban heating networks without seasonal heat storage reservoirs are EUR 28/MWh in 2030 and EUR 35/MWh in 2050. The estimated production costs for systems in rural areas with seasonal heat storage reservoirs are EUR 62/MWh (2030) or EUR 66/MWh (2050).

The **study by Jochum et al. (2017)** specifies a potential of 15.4 TWh/a for the ‘Trend’ scenario (corresponding to 3.7% of the useful heat demand in 2030) or 6.5 TWh/a (corresponding to 2.1% of the useful heat demand in 2050). The potential is 7.7 TWh/a for the ‘Committed climate action’ scenario (2.3% of the useful heating demand in 2030) or 1.1 TWh/a (0.6% of the useful heating demand in 2050). The study estimates the costs of supplying solar district or local heating at EUR 40/MWh. Jochum et al. (2017) follow Gerhardt et al. (2019) by modelling two scenarios; ‘conventional efficiency’ in the buildings sector is assumed for the ‘Trend’ scenario, whereas maximum efficiency resulting in an extremely ambitious drop in the consumption of useful heat is assumed for the ‘Ambitious’ scenario. The potentials calculated by Jochum et al. (2017) are lower in 2050 than in 2030. The message that emerges is that the consumption of useful heat has a major influence on potentials – a low level of consumption also means lower absolute potentials.

The **study ‘Climate pathways for Germany’ by Gerbert et al. (2018) on behalf of the Federation of German Industries [Bundesverband der Deutschen Industrie, BDI]** provides the following figures for solar thermal energy as a share of district heating production under the reference scenario: 4 TWh/a in 2030 and 8 TWh/a in 2050. The economic potentials specified for the 80% scenario are 8 TWh/a (2030) and 19 TWh/a (2050). The available potentials specified for the 90% scenario are 9 TWh/a (2030) and 20 TWh/a (2050). Comparatively low efficiency requirements are used as parameters in this study. This results in a drop in final energy consumption that is less marked than in other studies, and a doubling of potential between 2030 and 2050.

The study by Lauterbach et al. (2011) and the study ‘Pathways to a climate-neutral energy system’ by Sterchele et al. (2020) (carried out on behalf of the Fraunhofer ISE) are used to determine the solar thermal potentials for the production of industrial process heat. The technical potential for the solar thermal production of industrial process heat in the base year (2010) is 15.6 TWh/a for uses involving the production of heat up to a temperature of 250°C **(Lauterbach et al. 2011)**. Sterchele et al. (2020) specify the future technical and economic potentials as 3.7 TWh/a (2030) and 9.5 TWh/a (2050).

The potentials for large-scale production of grid-bound solar thermal heating and cooling are shown in Figure 12 for the years 2030 and 2050. Changes in heat demand in the buildings sector are also shown.

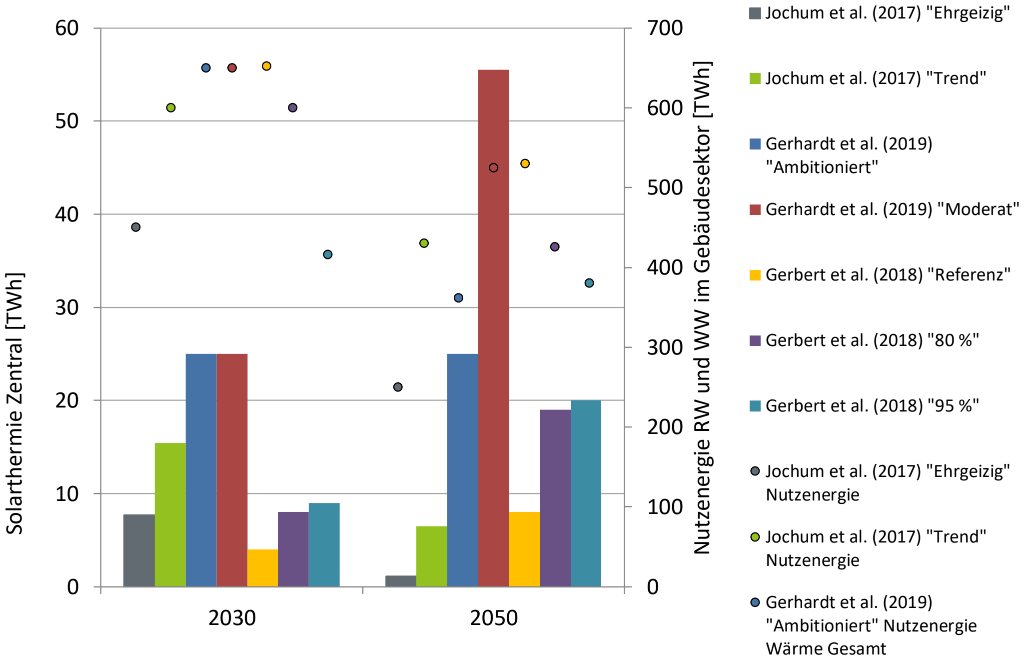


Figure 12: Comparison of economic solar thermal potentials for the years 2030 and 2050 based on the different scenarios outlined in three studies. (Own illustration on the basis of Jochum et al. (2017), Gerbert et al. (2019) and Gerhardt et al. (2019))

Solarthermie Zentral [TWh]	Centralised solar thermal energy [TWh]
Jochum et al. (2017) “Ehrgeizig”	Jochum et al. (2017) ‘Ambitious’
Jochum et al. (2017) “Trend”	Jochum et al. (2017) ‘Trend’
Gerhardt et al. (2019) “Ambitioniert”	Gerhardt et al. (2019) ‘Ambitious’
Gerhardt et al. (2019) “Moderat”	Gerhardt et al. (2019) ‘Moderate’
Gerhardt et al. (2018) “Referenz”	Gerhardt et al. (2018) ‘Reference’
Gerhardt et al. (2018) “80 %”	Gerhardt et al. (2018) ‘80%’
Gerhardt et al. (2018) “95 %”	Gerhardt et al. (2018) ‘95%’
Jochum et al. (2017) “Trend” Nutzenergie	Jochum et al. (2017) ‘Trend’, useful energy
Jochum et al. (2017) “Trend” Nutzenergie	Jochum et al. (2017) ‘Trend’, useful energy
Gerhardt et al. (2019) “Ambitioniert” Nutzenergie Wärme Gesamt	Gerhardt et al. (2019) ‘Ambitious’, useful energy for heating (total)

Background note: Production of cooling using large-scale solar systems

The heat from large-scale solar systems can also be used for the production of cooling using solar thermal energy. In this method, cold water is produced in closed-circuit procedures involving cooling processes with absorption or adsorption chillers. This can be fed into local or district cooling networks, for example, and used to cool buildings or to supply process cooling in the commercial and industrial sector. Final energy demand for the production of cooling in Germany is approximately 72 TWh/a at present, with a large proportion of this figure accounted for by industrial cooling and food production (Heinrich et al. 2014). Against the backdrop of a future rise in demand for cooling, solar cooling will gain significance not only for the construction of non-residential buildings, but also for the construction of premium-comfort residential buildings. Solar cooling benefits from the correlation between solar supply, ambient temperature and demand (Giovannetti et al. 2018). To a large extent, the potential of large-scale solar thermal energy for the production of cooling also depends on the future development of cooling networks. District cooling networks already exist in certain German cities (e.g. in Munich, Berlin, Hamburg, Dresden and Chemnitz). The demand for district cooling tends to be concentrated in densely populated urban areas, which places limitations on the amount of cooling that can be supplied by large-scale solar thermal systems.

Absorption chillers operate in a closed-circuit process involving a refrigerant that takes up heat from the surroundings through evaporation (cooling process) and is in turn absorbed by another liquid (the sorbent). The subsequent removal of the refrigerant from the sorbent requires the heat from the solar panel. Depending on the components used, it is possible to generate both positive cooling (>0 °C) and negative cooling (<0 °C). Depending on the set-up and the components used, thermal output figures (ratio of cooling supplied and heating input required) of 0.7-1.3 are typically achieved. This means that 0.7-1.3 kWh of cooling is produced from 1 kWh of heat (Preisler et al. 2013).

In adsorption chillers, a refrigerant (primarily water) is evaporated and accumulated in a porous solid. The solid body is then regenerated through the input of heat. Both refrigerant processes take place at the same time in two separate chambers within the adsorption chiller, which operates according to a cyclical, quasi-continuous operating principle.

5 Potential analysis for biomass, landfill gas, sewage gas and biogas

5.1 Introduction

The use of biomass to generate energy is currently a vital pillar of the renewable energy supply concept. Since biomass is easy to store, it is particularly suitable for the demand-oriented supply of energy and can therefore boost the security of supply in various sectors. Biomass currently dominates in certain sectors, in particular the renewable heating and cooling sector (86%, see Figure 13) and the transport sector (86%). In Germany, 50.4 TWh of electricity, 152.0 TWh of heat and 31.7 TWh of fuel were produced from biomass in 2019 (AGEE-Stat 2020). Of the 152.0 TWh of heat from biomass produced in 2019, 16.7 TWh (11.0%) are accounted for by biogas/biomethane, 2.5 TWh (1.6%) by sewage gas and 0.1 TWh (0.1%) by landfill gas (AGEE-Stat 2020). Sewage gas and landfill gas therefore only account for an extremely small share of the heat produced from biomass.

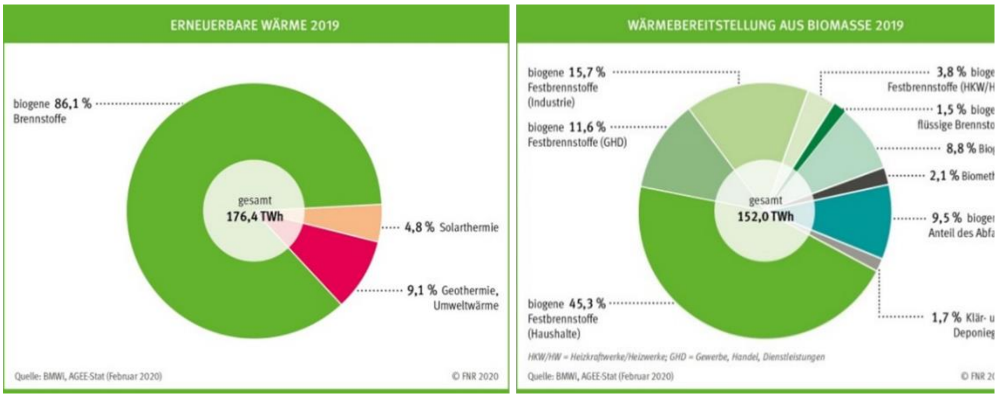


Figure 13: Supply of renewable heat (left) or heat from biomass (right) in Germany in 2019 (source: FNR 2020)

ERNEUERBARE WÄRME 2019	RENEWABLE HEAT 2019
biogene Brennstoffe	biogenic fuels
Solarthermie	solar thermal energy
Geothermie, Umweltwärme	geothermal energy, ambient heat
Quelle: BMWI, AGEE Stat (Februar 2020)	Source: BMWI, AGEE Stat (February 2020)
WÄRMEBEREITSTELLUNG AUS BIOMASSE 2019	HEAT SUPPLY FROM BIOMASS 2019
biogene Festbrennstoffe (Industrie)	biogenic solid fuels (industry)
biogene Festbrennstoffe (GHD)	biogenic solid fuels (commerce, trade, services)
biogene Festbrennstoffe (Haushalte)	biogenic solid fuels (households)
gestamt 152,0 TWh	total 152.0 TWh
biogene Festbrennstoffe (HKW/HW)	biogenic solid fuels (heating power plant/heating plant)
biogene flüssige Brennstoffe	biogenic liquid fuels
Biogas	biogas

Biomethan	biomethane
biogener Anteil des Abfalls	biogenic portion of waste
Klär- und Deponiegas	sewage gas and landfill gas
HKW/HW – Heizkraftwerke/Heizwerke	
GHD – Gewerbe, Handel, Dienstleistungen	
Quelle: BMWI, AGEE Stat (Februar 2020	Source: BMWI, AGEE Stat (February 2020)

RED II defines the term **biomass** as, '*the biodegradable fraction of products, waste and residues from biological origin from agriculture, including vegetal and animal substances, from forestry and related industries, including fisheries and aquaculture, as well as the biodegradable fraction of waste, including industrial and municipal waste of biological origin*'. Similarly, it defines the term **biogas** as, *'gaseous fuels that are produced from biomass'*. Although the terms **landfill gas** and **sewage gas** are not defined as such in RED II, they are evidently covered by the phrase, '*the biodegradable fraction of waste, including industrial and municipal waste of biological origin*'.

This makes it clear that biomass is the umbrella term and that landfill gas, sewage gas and biogas are all subsets thereof. Landfill gas and sewage gas qualify as waste, whereas biogas can be obtained both from residues and waste (e.g. agricultural residues such as slurry or waste from the food industry) and from cultivated biomass (renewable raw materials).

Classification and competition with other technologies/heat sources

Controversy rages over the use of biomass to generate energy, in particular the use of cultivated biomass (renewable raw materials). The latter may result in conflicts of interest with food and feed supply structures (fuel or food debate) as well as land-use changes that may have a negative impact not only on the greenhouse gas balance of the bioenergy sources, but also on the conservation of biodiversity. Although biomass is a renewable resource, the availability of sustainable biomass is limited, meaning that corresponding restrictions must be imposed on its use (Fehrenbach & Rettenmaier 2020)**.**

Definition of biomass potential and procedure for analysing potential in the biomass sector

It is important to be able to assess the future availability within a given geographical unit of biomass that can be used as an energy source or material, since this assessment serves as a basis for socio-political decisions. Biomass potential studies that calculate biomass potential using scenario-based approaches are typically produced for this purpose. The literature contains a great many studies of this kind relating to different geographical reference areas (ranging from global to local level).

Biomass potential studies typically quantify the **technical biomass potential**, since this fluctuates significantly less over time than the economic potential, for example. The technical biomass potential is the share of the theoretical potential that can be used in view of the given technical restrictions (e.g. recovery rate, conversion losses). Consideration is also given to the structural and legally enshrined restrictions that exist in relation to ecological or other issues, since these are ultimately also 'insurmountable' in a similar way to the technical restrictions (Thrän & Pfeiffer 2013).

As a general rule, the studies specify the **fuel potential** of the biomass, which typically corresponds to the lower calorific value of the solid biomass (solid fuels) and the liquid or gaseous secondary energy sources (liquid and gaseous fuels) (Kaltschmitt et al. 2003; Thrän & Pfeiffer 2013). The justification for doing so is that vegetal biomass (depending on its substrate properties) must be converted into solid, liquid or gaseous bioenergy sources using more or less complex procedures. Ligneous biomass requires minimal processing before being used for energy-related purposes, whereas wetter biomass types are only suitable as substrates for energy-related uses after pre-treatment.

In turn, there are various potential uses for the different bioenergy sources within the energy system (electricity, heat, fuel). In many of the biomass potential studies examined in Section 5.2, however, the technical potential is not allocated to the individual consumption sectors, which means that no bioenergy potential is specified. This potential reflects the share of final energy that is supplied after conversion for the individual use pathways (Thrän & Pfeiffer 2013). Certain studies do carry out allocations of this kind, but often in the form of various 100:0 allocations (e.g. Gerhardt et al. 2015).

Fehrenbach et al. (2019) perform an allocation on the basis of qualitative and semi-quantitative criteria. In most cases, however, the fuel potential is 'translated' into a bioenergy potential by means of mathematical models in 'energy scenario studios'. Economic optimisation of biomass use and the allocation of biomass to the individual consumption sectors is typically performed on the basis of models, i.e. the **economic potentials** are specified. The results depend to a large extent on the framework data and framework assumptions that feed into the respective models. Certain individual studies such as Koch et al. (2018) or Thrän et al. (2020) furthermore specify the sectoral shares from an exogenic perspective before the economic optimisation stage (e.g. electricity and heat production versus traffic).

With this in mind, Section 5.2 below indicates the total fuel potentials of biomass *before* allocation to the individual consumption sectors (e.g. to the heating and cooling supply sector). Given that the different uses are competing for the limited resource of biomass, an allocation of this kind and the specification of a technical potential is only possible if additional criteria are used. This typically takes place by means of model-based economic optimisation, and so the resulting figures are economic potentials. Section 5.3 below therefore outlines the results of various cross-sector (energy scenario) studies and the resulting range of economic potentials.

5.2 Fuel potentials for biomass

The potentials analysed below are broken down into residues and waste on the one hand and cultivated biomass on the other. **Imported biomass is explicitly excluded from this analysis**, but included in the overview for the sake of completeness. In the first place, biomass imports are highly controversial for sustainability-related reasons, since they may result in land use conflicts and land-use changes in other countries; secondly, the report is explicitly designed to present the *national* potentials of renewable energies.

Residues and waste

Biogenic residues include material flows from agriculture and forestry (e.g. slurry, residual straw or residual forest wood) and from biomass-processing industry (food industry, wood industry, paper industry and furniture industry) that are not the main product of the manufacturing process. Since the unambiguous identification of 'real' waste is not always possible (see comments by Thrän & Pfeiffer 2013), these material flows are often examined jointly.

The literature contains many studies that estimate the domestic potential from residues and waste at approximately 700 to 900 PJ/a. Many of these studies make use of the pioneering work carried out by Fritsche et al. (2004) and Nitsch et al. (2004), which was cited extensively over a 10-year period (Kirchner et al. (2009), Thrän et al. (2010), Nitsch et al. (2012), Gerhardt et al. (2015)). Gerhardt et al. (2015) apply a deduction and estimate a potential of 625 PJ/a. The long-term scenarios (Pfluger et al. 2017) also make use of the scenarios in Nitsch et al. (2004), namely the 'Nature Conservation Plus' scenario that specifies a figure of just over 700 PJ/a.

The study by Brosowski et al. (2015) was the first original new study on the status quo of the biomass potentials of residues and waste that had been published for some years. This study examines 93 individual biomasses and estimates their potential at a total of 989 PJ/a (of which 541 PJ/a is currently used and 448 PJ/a is unused). In turn, this work formed the basis for a web-based resource database (DBFZ 2019) and for the study by Thrän et al. (2019), who specify a potential of 876 PJ/a (plus 150 PJ/a in the form of logs). Thrän et al. (2020) even specify a potential of over 1 000 PJ/a from 2030 onwards, which is only exceeded by Koch et al. (2018), who estimate a potential of over 1 100 PJ/a. The bioeconomy monitoring study of Bringezu et al. (2020) is also based on the aforementioned resource database and on the outcomes of the Working Group on Biomass Residue Monitoring (Brosowski et al. 2019), and shows a technical biomass potential of up to 1 000 PJ/a, of which 66-84% is already established in use. Three quarters (75%) of the additional residue potential that can be mobilised originates from five individual biomasses: cereals straw, cattle slurry, residual forest wood (coniferous), cattle manure and green waste.

In the 'BioRest' study, Fehrenbach et al. (2019) examine 24 individual biomasses and calculate a potential of around 900 PJ/a, of which approximately 770 PJ/a (85%) is already being used for energy-related purposes today. The study also contains a comprehensive use concept based on qualitative and semi-quantitative criteria, thereby classifying residues and waste into consumption sectors. Straw and solid manure are identified as a source of possible additional residue potentials to be mobilised, whereas forest wood is deemed to be overused (Fehrenbach & Rettenmaier 2020). In turn, Purr et al. (2019) base their work on the potential calculated by Fehrenbach et al. (2019), while other premises are posited by the RESCUE study; for example, straw is not available for the generation of electricity and heat, but is instead converted into bioethanol. These premises mean that the potential specified in the RESCUE study is significantly lower.

Cultivated biomass (renewable raw materials)

Cultivated biomass includes not only biomass that is cultivated as a material, but also biomass that is cultivated for energy-related purposes. Renewable raw materials are cultivated on agricultural land and include both annual crops and perennial grasses and wood from short-rotation plantations. At present, around 20% of arable land in Germany is used for the cultivation of renewable raw materials. Biomass potential studies typically calculate a land potential for renewable raw materials which prioritises the land required for cultivating food and feed crops; they estimate very different levels of self-sufficiency, which in some cases results in significant virtual land imports.

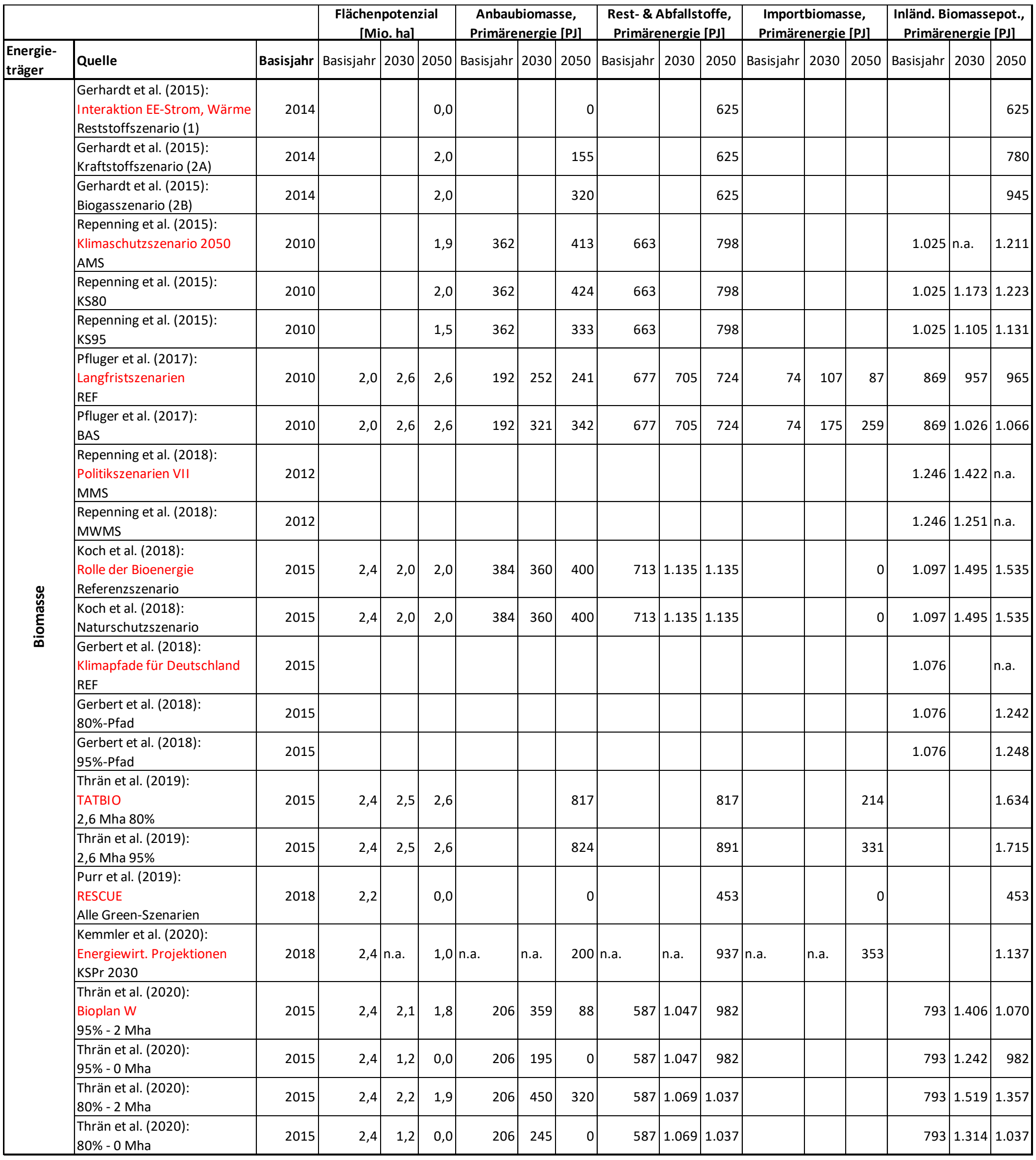
The literature contains a great many studies with widely diverging estimates of the land potential for cultivated biomass. The range extends from 0 million ha to 7 million ha in Germany (Zeddies et al. 2012). In turn, the pioneering and much-cited studies by Fritsche et al. (2004) and Nitsch et al. (2004) specify figures of up to 4.2 million ha. The studies used as a basis for this analysis in this report estimate a land potential of between 0 million ha (Gerhardt et al. 2015, Purr et al. 2019, Thrän et al. 2019, 2020) and 4 million ha (Thrän et al. 2019) for 2050. Multiple estimated land potentials are often used in the same study; for example, the TATBIO study (Thrän et al. 2019) investigates three scenarios and specifies figures of 1.0 million ha, 2.6 million ha (based on Pfluger et al. 2017) and 4.0 million ha for energy crops. Other studies, such as the RESCUE study which was also published in 2019 (Purr et al., 2019), exclude any cultivation of biomass for energy-related purposes after 2030. Table 6 uses a maximum figure of 2.6 million ha for all studies, since it can be assumed (according to the Climate Action Programme 2030) that there will be no further increase in cultivated land.

The resulting fuel potential from cultivated biomass (renewable raw materials) therefore varies greatly between the studies; the range extends from 0 to over 800 PJ/a (see Table 6). As regards the high values obtained for the TATBIO study (Thrän et al. 2019), it should also be noted that this study assumes the use of a crop mix based predominantly on Miscanthus, which has a very high average energy yield per area unit. It is however possible that such a high proportion of perennial plants (such as Miscanthus) would restrict crop rotation design options on the arable land as a whole.

Overview of data sources

Table 6 below compares the fuel potentials estimated by the selected data sources. Imported biomass is explicitly excluded from this analysis, but included in Table 6 for the sake of completeness. The domestic biomass potential shown in the last three columns therefore only includes (domestic) residues and waste and (domestic) cultivated biomass.

Table 6: Overview of the literature in the biomass-produced heating and cooling sector: fuel potentials. The base year relates to the year in which the data for the studies were collected; older preliminary surveys were used for some studies.



			Flächenpotenzial [Mio. ha]			Anbaubiomasse, Primärenergie [PJ]			Rest- & Abfallstoffe, Primärenergie [PJ]			Importbiomasse, Primärenergie [PJ]			Inländ. Biomassepot., Primärenergie [PJ]		
Energieträger	**Quelle**	**Basisjahr**	Basisjahr	2030	2050	Basisjahr	2030	2050	Basisjahr	2030	2050	Basisjahr	2030	2050	Basisjahr	2030	2050
Biomasse	Gerhardt et al. (2015): Interaktion EE-Strom, Wärme Reststoffszenario (1)	2014			0,0			0			625						625
	Gerhardt et al. (2015): Kraftstoffszenario (2A)	2014			2,0			155			625						780
	Gerhardt et al. (2015): Biogasszenario (2B)	2014			2,0			320			625						945
	Repenning et al. (2015): Klimaschutzszenario 2050 AMS	2010			1,9	362		413	663		798				1.025	n.a.	1.211
	Repenning et al. (2015): KS80	2010			2,0	362		424	663		798				1.025	1.173	1.223
	Repenning et al. (2015): KS95	2010			1,5	362		333	663		798				1.025	1.105	1.131
	Pfluger et al. (2017): Langfristszenarien REF	2010	2,0	2,6	2,6	192	252	241	677	705	724	74	107	87	869	957	965
	Pfluger et al. (2017): BAS	2010	2,0	2,6	2,6	192	321	342	677	705	724	74	175	259	869	1.026	1.066
	Repenning et al. (2018): Politikszenarien VII MMS	2012													1.246	1.422	n.a.
	Repenning et al. (2018): MWMS	2012													1.246	1.251	n.a.
	Koch et al. (2018): Rolle der Bioenergie Referenzszenario	2015	2,4	2,0	2,0	384	360	400	713	1.135	1.135			0	1.097	1.495	1.535
	Koch et al. (2018): Naturschutzszenario	2015	2,4	2,0	2,0	384	360	400	713	1.135	1.135			0	1.097	1.495	1.535
	Gerbert et al. (2018): Klimapfade für Deutschland REF	2015													1.076		n.a.
	Gerbert et al. (2018): 80%-Pfad	2015													1.076		1.242
	Gerbert et al. (2018): 95%-Pfad	2015													1.076		1.248
	Thrän et al. (2019): TATBIO 2,6 Mha 80%	2015	2,4	2,5	2,6			817			817			214			1.634
	Thrän et al. (2019): 2,6 Mha 95%	2015	2,4	2,5	2,6			824			891			331			1.715
	Purr et al. (2019): RESCUE Alle Green-Szenarien	2018	2,2		0,0			0			453			0			453
	Kemmler et al. (2020): Energiewirt. Projektionen KSPr 2030	2018	2,4	n.a.	1,0	n.a.	n.a.	200	n.a.	n.a.	937	n.a.	n.a.	353			1.137
	Thrän et al. (2020): Bioplan W 95% - 2 Mha	2015	2,4	2,1	1,8	206	359	88	587	1.047	982				793	1.406	1.070
	Thrän et al. (2020): 95% - 0 Mha	2015	2,4	1,2	0,0	206	195	0	587	1.047	982				793	1.242	982
	Thrän et al. (2020): 80% - 2 Mha	2015	2,4	2,2	1,9	206	450	320	587	1.069	1.037				793	1.519	1.357
	Thrän et al. (2020): 80% - 0 Mha	2015	2,4	1,2	0,0	206	245	0	587	1.069	1.037				793	1.314	1.037

Flächenpotenzial [Mio. ha]	Land potential [million ha]
Anbaubiomasse, Primärenergie [PJ]	Cultivated biomass, primary energy [PJ]
Rest- & Abfallstoffe, Primärenergie [PJ]	Residues and waste, primary energy [PJ]
Importbiomasse, Primärenergie [PJ]	Imported biomass, primary energy [PJ]
Inländ. Biomassepot., Primärenergie [PJ]	Domestic biomass potential, primary energy [PJ]
Energieträger	Energy source
Quelle	Source
Basisjahr	Base year
Biomasse	Biomass
Gehardt et al. (2015): Interaktion EE-Strom, Wärme Reststoffszenario (1)	Gerhardt et al. (2015): Interaction with RES electricity, heat Residue scenario (1)

Gehardt et al. (2015): Kraftstoffszenario (2A)	Gerhardt et al. (2015): Fuel scenario (2A)
Gehardt et al. (2015): Biogasszenario (2B)	Gerhardt et al. (2015): Biogas scenario (2B)
Repenning et al. (2015): Klimaschutzszenario 2050 AMS	Repenning et al. (2015): Climate action scenario 2050 Current measures scenario
Repenning et al. (2015): KS80	Repenning et al. (2015): Climate action 80%
Repenning et al. (2015): KS95	Repenning et al. (2015): Climate action 95%
Pfluger et al. (2017): Langfristzenarien REF	Pfluger et al. (2017): Long-term scenarios Reference
Pfluger et al. 2017: BAS	Pfluger et al. 2017: Baseline
Repenning et al. (2018): Politikszenarien VII MMS	Repenning et al. (2018): Policy scenarios VII With measures scenario
Repenning et al. (2018): MWMS	Repenning et al. (2018): With further measures scenario
Koch et al. (2018) Rolle der Bioenergie Referenzszenario	Koch et al. (2018) Role of bioenergy Reference scenario
Koch et al. (2018) Naturschutzszenario	Koch et al. (2018) Nature conservation scenario
Gerbert et al. (2018): Klmapfade für Deutschland REF	Gerbert et al. (2018): Climate pathways for Germany Reference
Gerbert et al. (2018): 80%-Pfad	Gerbert et al. (2018): 80% pathway
Gerbert et al. (2018) 95%-Pfad	Gerbert et al. (2018) 95% pathway
Thrän et al. (2019) TATBIO 2,6 Mha 80%	Thrän et al. (2019) TATBIO 2.6 Mha 80%
Thrän et al. (2019): 2,6 Mha 95%	Thrän et al. (2019): 2.6 Mha 95%
Purr et al (2019): RESCUE Alle Green-Szenarien	Purr et al (2019): RESCUE All green scenarios
Kemmler et al. (2020): Energiewirt Projektionen KSPr 2030	Kemmler et al. (2020): Energy farmer projections Climate action programme 2030
Thrän et al. (2020): Bioplan W 95% - 2 Mha	Thrän et al. (2020): ‘Bioplan W’ 95% - 2 Mha
Thrän et al. (2020): 95%	Thrän et al. (2020): 95%
Thrän et al. (2020): 80% - 2 Mha	Thrän et al. (2020): 80% - 2 Mha

Thrän et al. (2020): 80% - 0 Mha	Thrän et al. (2020): 80% - 0 Mha

The figures are visualised in Figure 14.

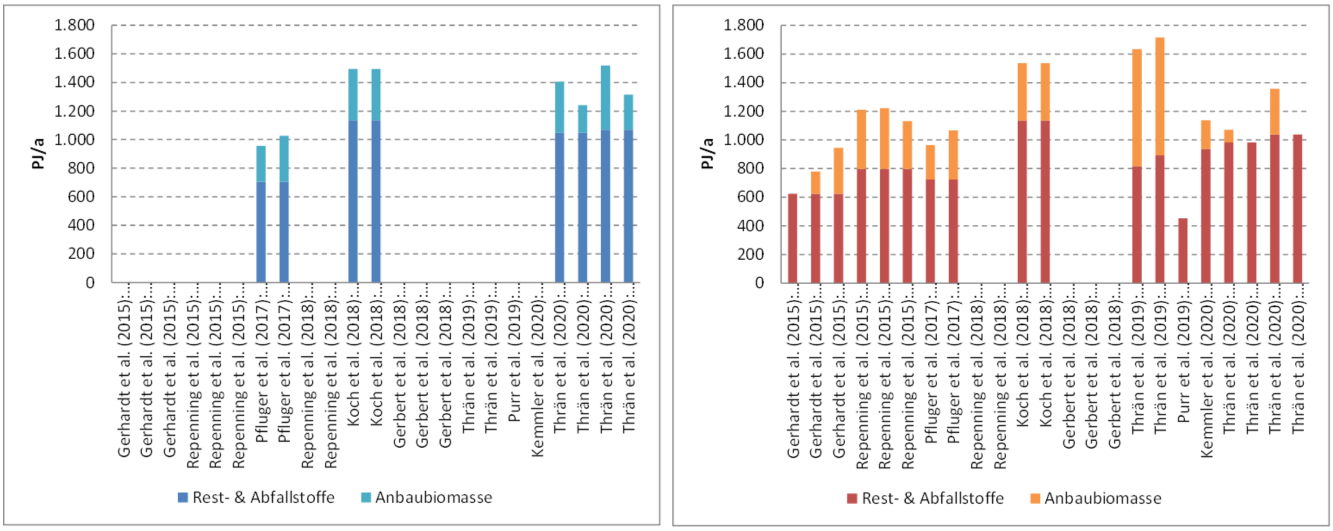


Figure 14: Fuel potentials of residues and waste and cultivated biomass for 2030 (left) and 2050 (right) in different biomass potential studies and scenarios

PJ/a	PJ/a
Rest- & Abfallstoffe	Residues and waste
Anbaubiomasse	Cultivated biomass

In spite of certain differences and the limited comparability of the studies (e.g. collection of data regarding individual biomasses versus aggregated material flows), the overall picture of the fuel potentials of residues and waste that emerges from all the studies is remarkably uniform. The more recent studies specify a range extending from 800 to 1 100 PJ/a, which suggests a high level of uncertainty, in particular as regards the respective estimates of water or dry matter content, animal-specific manure volumes and the recovery rate of residual forest wood. The figure of 1 000 PJ/a specified in the bioeconomy monitoring study could be used as a benchmark. At the same time, however, between two thirds and 85% of the potential is already being used for energy-related purposes.

A very different situation applies in the case of cultivated biomass; the land potentials for cultivated biomass vary greatly across all the studies examined, ranging from 0 million ha (Gerhardt et al. 2015, Purr et al. 2019, Thrän et al. 2019, 2020) all the way up to 4 million ha (Thrän et al. 2019), although the majority lie between 1.0 million ha and 2.6 million ha. This can be attributed to the use of different scenario assumptions concerning demographic trends, dietary habits (in particular meat consumption) and yield increases (Rettenmaier et al. 2010). These parameters are extremely sensitive and have a direct impact on the land available for other purposes. It follows that the resulting fuel potential from cultivated biomass (renewable raw materials) also varies enormously between studies, with a range extending from 0 to over 800 PJ/a (or even 1 267 PJ/a at 4.0 million ha for one scenario in

Thrän et al. 2019); most studies lie within a range of approximately 200 to 400 PJ/a, however.

5.3 Total heating and cooling potential and classification

This section opens with a discussion of the range of economic potentials for biomass in Germany (in Table 7). In line with the definition in the Directive, explicit reference is made to the sub-quantities for landfill gas, sewage gas and biogas for 2030. The procedure followed to calculate the potentials is explained below.

Table 7: Overview of results of potential analysis for biomass (with reference to final energy)

Energy source (TWh/a)	Economic potential	
	2030	**2050**
Biomass Of which:	**60-185**	**16-187**
Landfill gas	**0**	
Sewage gas	**3**	
Biogas	**0-65**	

Competition for uses of biomass (i.e. situations where a resource can be used for multiple different purposes in the various consumption sectors, but the availability of that resource is restricted) mean that a *technical* potential for heating and cooling can only be specified on the basis of additional criteria. In most cases, the fuel potential is 'translated' into a bioenergy potential in 'energy scenario studies', which are typically based on economic optimisation of the biomass use by means of an underlying mathematical model. It follows that the figures specified in these studies are **economic potentials**. The range of total heating and cooling production from biomass in 2030 extends from 60 TWh/a to 185 TWh/a, with the lower extent of the range dropping even further in 2050 to 16 TWh/a (see Figure 15). This also includes landfill gas, sewage gas and biogas.

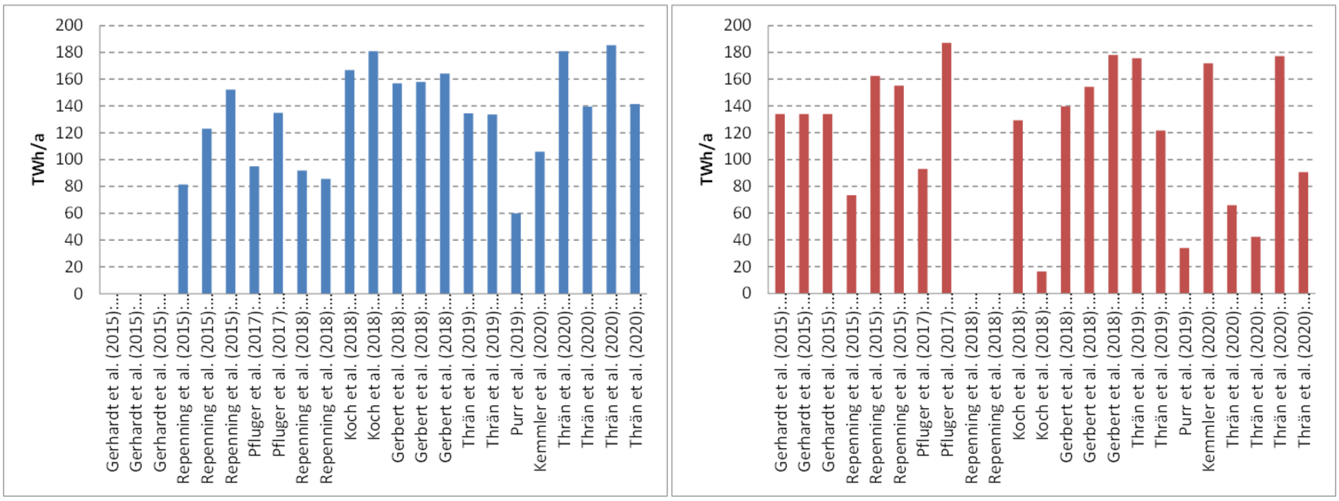


Figure 15: Economic potentials for heat from biomass in 2030 (left) and 2050 (right) based on various studies and scenarios

TWh/a	TWh/a

Landfill gas and sewage gas potentials (fuel potentials) are explicitly specified in only a small number of biomass potential studies. By way of contrast, the economic potential for heating and cooling from landfill gas and sewage gas is not specified separately in any of the energy scenario studies included in the analysis. In the best case, a distinction is made between heating and cooling from solid and gaseous biomass (although biogas from cultivated biomass and in some cases also sewage gas is then included). Given the small numbers involved, it is proposed that future heating and cooling production from landfill gas and sewage gas should be estimated in proportion to biomass potentials, in line with the approach followed by Fehrenbach et al. (2019). The studies analysed in Fehrenbach et al. (2019) suggest that the production of usable landfill gas in Germany will cease completely by 2030 at the latest. This results in an economic potential of 0 TWh/a from landfill gas and around 2.6 TWh/a from sewage gas for 2030.

Technical biogas potentials (fuel potentials) are typically listed separately in biomass potential studies; the breakdown is often carried out on the basis of residues and waste or cultivated biomass (renewable raw materials). It is evident that the biogas potentials from residues and waste specified by all of the studies lie within a comparable range, whereas the biogas potential from cultivated biomass varies enormously depending on the land potentials, cultivation mixes and utilisation pathways estimated in each case. Unfortunately, very few energy scenario studies list the economic potential for heating and cooling from gaseous biomass separately (data gap). The figure for 2030 lies in a range of between 0 TWh/a and 65 TWh/a.

In view of the current level of use (approximately 150 TWh/a), it cannot therefore be assumed that total biomass potential will increase significantly in future; instead, the opposite is true. Increasingly fierce competition over land and other uses of biomass, as well as the challenges involved in replacing biomass in other sectors (‘lack of alternatives’), combined with the debates about more sustainable agriculture (large-scale biodiversity loss, virtual land imports, in particular for the purpose of filling the protein gap, etc.) are taken into consideration to very different degrees in the energy scenario studies that are examined, meaning that questions must be raised in particular about the future potentials from cultivated biomass. For example, the most recent calculations by Rettenmaier & Köppen (not yet published) refer to an area for cultivation of renewable raw materials of ‘only’ 1 million ha in 2050, based on the Long-Term Scenario 3 and subject to the proviso of adequate land availability in balance sheet terms at the same time as a significant (-33%) reduction in meat consumption. Particular attention should therefore be paid to the lower end of the ranges shown in Table 7.

Table 8 provides a detailed overview of the contents of the studies.

Table 8: Overview of the literature in the biomass-produced heating and cooling sector: Economic potentials. The base year relates to the year in which the data for the studies were collected; older preliminary surveys were used for some studies.

					Sektoren			**Anwendung**			**Wirtschaftl. Potential Wärme & Kälte [TWh]**		
Energieträger	**Quelle**	**Basisjahr**	**Wärme**	**Kälte**	HH	GHD	Ind	WW	RW	PW	Basisjahr	2030	2050
Biomasse	Gerhardt et al. (2015): Interaktion EE-Strom, Wärme Reststoffszenario (1)	2014	ja		x	x	x	x	x		n.a.	n.a.	134
	Gerhardt et al. (2015): Kraftstoffszenario (2A)	2014	ja		x	x	x	x	x		n.a.	n.a.	134
	Gerhardt et al. (2015): Biogasszenario (2B)	2014	ja		x	x	x	x	x		n.a.	n.a.	134
	Repenning et al. (2015): Klimaschutzszenario 2050 AMS	2010	ja	nein	x	x	x	x	x	x	79	81	73
	Repenning et al. (2015): KS80	2010	ja	nein	x	x	x	x	x	x	79	123	163
	Repenning et al. (2015): KS95	2010	ja	nein	x	x	x	x	x	x	79	152	155
	Pfluger et al. (2017): Langfristszenarien REF	2010	ja		x	x	x	x	x	x	108	95	93
	Pfluger et al. (2017): BAS	2010	ja		x	x	x	x	x	x	108	135	187
	Repenning et al. (2018): Politikszenarien VII MMS	2012	ja		x	x	x	x	x		83	92	n.a.
	Repenning et al. (2018): MWMS	2012	ja		x	x	x	x	x		83	86	n.a.
	Koch et al. (2018): Rolle der Bioenergie Referenzszenario	2015	ja		x	x	x	x	x	x	96	167	129
	Koch et al. (2018): Naturschutzszenario	2015	ja		x	x	x	x	x	x	96	181	16
	Gerbert et al. (2018): Klimapfade für Deutschland REF	2015	ja		x	x	x	x	x	x		157	140
	Gerbert et al. (2018): 80%-Pfad	2015	ja		x	x	x	x	x	x		158	154
	Gerbert et al. (2018): 95%-Pfad	2015	ja		x	x	x	x	x	x		164	178
	Thrän et al. (2019): TATBIO 2,6 Mha 80%	2015	ja		x	x	x	x	x	x	ca. 150	135	176
	Thrän et al. (2019): 2,6 Mha 95%	2015	ja		x	x	x	x	x	x	ca. 150	134	122
	Purr et al. (2019): RESCUE Alle Green-Szenarien	2018	ja	ja	x	x	x	x	x	x	132	60	34
	Kemmler et al. (2020): Energiewirt. Projektionen KSPr 2030	2018	ja		x	x	x	x	x	x	90	106	172
	Thrän et al. (2020): Bioplan W 95% - 2 Mha	2015	ja		x	x	x	x	x	x	66	181	66
	Thrän et al. (2020): 95% - 0 Mha	2015	ja		x	x	x	x	x	x	66	140	42
	Thrän et al. (2020): 80% - 2 Mha	2015	ja		x	x	x	x	x	x	66	185	177
	Thrän et al. (2020): 80% - 0 Mha	2015	ja		x	x	x	x	x	x	66	142	90

Sektoren	Sectors
Anwendung	Application
Wirtschaftl. Potential Wärme & Kälte [TWh]	Economic heating and cooling potential [TWh]
Energieträger	Energy source

Quelle	Source
Basisjahr	Base year
Wärme	Heating
Kälte	Cooling
Biomasse	Biomass
HH	Households
GHD	Commerce, trade and services
Ind	Industry
WW	Hot water
RW	Space heating
PW	Process heat
Basisjahr	Base year
Gehardt et al. (2015): Interaktion EE-Strom, Wärme Reststoffszenario (1)	Gerhardt et al. (2015): Interactions between renewable electricity, heating Residue scenario (1)
Gerhardt et al. (2015): Kraftstoffszenario (2A)	Gerhardt et al. (2015): Fuel scenario (2A)
Gehardt et al. (2015): Biogasszenario (2B)	Gerhardt et al. (2015): Biogas scenario (2B)
Repenning et al. (2015): Klimaschutzszenario 2050: AMS	Repenning et al. (2015): Climate protection scenario 2050: Current measures scenario
Repenning et al. (2015): KS80	Repenning et al. (2015): Climate action 80%
Repenning et al. (2015): KS95	Repenning et al. (2015): Climate action 95%
Pfluger et al (2017): Langfristszenarien REF	Pfluger et al (2017): Long-term scenarios Reference
Pfluger et al. (2017): BAS	Pfluger et al. (2017): Baseline
Repenning et al. (2018): Politikszenarien VII MMS	Repenning et al. (2018): Policy scenarios VII With measures scenario
Repenning et al. (2018): MWMS	Repenning et al. (2018): With further measures scenario
Koch et al. (2018) Rolle der Bioenergie Referenzszenario	Koch et al. (2018) Role of bioenergy Reference scenario
Koch et al. (2018) Naturschutzszenario	Koch et al. (2018) Nature conservation scenario
Gerbert et al. (2018): Klmapfade für Deutschland REF	Gerbert et al. (2018): Climate pathways for Germany Reference
Gerbert et al. (2018): 80%-Pfad	Gerbert et al. (2018): 80% pathway
Gerbert et al. (2018) 95%-Pfad	Gerbert et al. (2018) 95% pathway

Thrän et al. (2019) TATBIO 2,6 Mha 80%	Thrän et al. (2019) TATBIO 2.6 Mha 80%
Thrän et al. (2019): 2,6 Mha 95%	Thrän et al. (2019): 2.6 Mha 95%
Purr et al (2019): RESCUE Alle Green-Szenarien	Purr et al (2019): RESCUE All green scenarios
Kemmler et al. (2020): Energiewirt Projektionen KSPr 2030	Kemmler et al. (2020): Energy farmer projections Climate action programme 2030
Thrän et al. (2020): Bioplan W 95% - 2 Mha	Thrän et al. (2020): ‘Bioplan W’ 95% - 2 Mha
Thrän et al. (2020): 95%	Thrän et al. (2020): 95%
Thrän et al. (2020): 80% - 2 Mha	Thrän et al. (2020): 80% - 2 Mha
Thrän et al. (2020): 80% - 0 Mha	Thrän et al. (2020): 80% - 0 Mha

6 Potential analysis for ambient energy

The following use cases are examined separately for the purpose of analysing potentials in the field of ambient energy:

- use of ambient energy in individual buildings by means of air-source heat pumps (see Section 6.1),
- centralised use of ambient energy in heating networks by means of air-source heat pumps (see Section 6.2),
- use of energy from surface water in heating networks (see Section 6.3),
- use of energy from waste water (see Section 6.4).

6.1 Decentralised ambient air

6.1.1 Introduction

Despite its low temperature, ambient air can be used to supply space heating and hot water. Air/water-source heat pumps (also known as air-source heat pumps) are used for this purpose. They extract heat from ambient air using high-capacity heat exchangers with ventilators for the evaporation of refrigerant. The refrigerant vapour is condensed in the compressor of the heat pump, becomes liquid again and emits the heat that has been produced as useful heat. Different designs are available; in some, the evaporator and compressor are accommodated in a single housing, whereas in others (referred to as ‘split’ designs) the evaporator can be installed at another suitable location that is geographically distant from the compressor, in which case the refrigerant is transported to the compressor through pipes. Air-source heat pumps for decentralised use in individual buildings are available with heat outputs of up to approximately 30 kW. They are primarily used in single-family dwellings and small multi-family dwellings. If higher outputs are required, several devices can be placed in a cascade arrangement.

Air is an inexhaustible source of heat, and is not subject to any heat source-specific restrictions. The efficiency of heat pumps depends only on fluctuations in air temperature. The coefficient of performance for air-source heat pumps drops significantly at low air temperatures, meaning that electricity consumption rises on cold days. The high degree of concurrency with which this peak demand occurs means that the electricity distribution system is subject to greater demand in districts with a high share of air-source heat pumps. To counteract this, electricity suppliers offer heat pump tariffs with up to three lockout periods per day, lasting up to two hours. According to the distribution system operators, a high share of heat pumps is unlikely to have a significant impact on the electricity network (Jochum et al., 2017). Scenarios that provide for a high share of heat pumps always involve the massive expansion of distribution systems. Depending on the scenario framework, up to 10-25% of this expansion is caused by a growth in the number of heat pumps. Further drivers for network expansion include e-mobility and photovoltaic systems (Mellwig et al., 2018).

The noise of fluid flowing through the ventilators in air heat exchangers can be perceived as irritating. The installation locations, alignments and shielding of individual devices play a role in determining whether noise immissions exceed the limit values laid down in the Technical Guidelines for Noise Reduction [Technische Anleitung zum Schutz gegen Lärm, TA Lärm]. In residential areas, daytime noise immissions must be below 50 dB(A), and night-time noise immissions must be below 35 dB(A). They are measured in the centre of the window. Noise emissions from modern air heat pumps are approximately 55 dB(A), which means that they must be installed at a minimum distance of 10 metres from any windows. Medical studies have furthermore confirmed that noise immissions at levels as low as 25 dB(A) over a protracted period can mean that night-time sleep is less restorative (LfU, 2004). A distance between the heat pump and any windows of over 30 metres would be necessary to comply with this value. Distances of this magnitude cannot always be guaranteed, particularly in urban residential areas. In densely built-up areas, mutual interference between the noise immissions of multiple air-source heat pumps may also occur. This may result in a reciprocal increase in the acoustic pressure level on a locally restricted basis (Eulitz et al. 2019). The level of interference depends not only on the interactions between multiple air-source heat pumps, but also on the extent to which the area is built up and other sources of noise that are present. It cannot be attributed to a single noise source. Heat pump manufacturers are aware of the problems relating to noise, and therefore also offer acoustic enclosures for their pumps that can reduce emissions by up to 10 dB. They also use higher-capacity heat exchangers with slower flow speeds or specially designed ventilators, for example. Designs that discharge air upwards or in which the evaporator is located within the building also reduce emissions of noise. Jochum et al. (2017) do not calculate any technical potential limits on the basis of the noise emissions of the heat pumps, since it is assumed that future heat pump generations will be improved from a technical perspective, and that specific noise control solutions will be found in concrete individual cases.

6.1.2 Total heating and cooling potential and classification

The restrictions resulting from the transfer of heat to the space in rooms apply to air-source heat pumps to the same extent as to all heat pumps. In buildings that are not adequately insulated, the required flow temperature in the heating system is so high that it cannot be achieved by a heat pump in an economically feasible manner. To a certain extent, this can be mitigated through the replacement of radiators. According to Jochum et al. (2017), the economically feasible operation of heat pumps is not possible above a useful heat demand of 120 kWh/m²a. This limit only applies if ideal conditions are present in the heating circuits, however. If the available radiators are not all calibrated to the same specific heat load or are not balanced, or if individual rooms require a higher flow temperature owing to an exposed location or higher setpoint temperatures, the threshold for the use of heat pumps drops yet further. In practice, heat pumps can almost never be installed in buildings with a heating demand above 90 kWh/m²a. Jochum et al. (2017) state that – depending on how ambitious future efforts to increase building efficiency are – the annual market share of heat pumps in 2050 could be increased to 88-98% of the heat generators to be replaced on an annual basis, subject to this restriction. This would make the corresponding share of total useful heat consumption by the building stock in 2050 around 78-93% (176-242 TWh). **For 2030, this technical potential is 260-267 TWh.** To exploit this potential in full, it will be necessary to install a heat pump in all buildings suitable for this purpose. This presupposes a sharp rise in the market share of heat pumps, which was 11.5% of installed heat sources in 2018. The maximum market ramp-up speed imposes additional restrictions; these are heavily influenced by demand as well as being extremely volatile. The restrictions are therefore not quantified in this report. They apply not only to air-source heat pumps, but to all types of decentralised heat pumps. The specific potential of air-source heat pumps is not further delimited, since this would require an assessment of future changes in the market shares held by the different heat pump types. The aforesaid potential only applies to the extreme case in which all heat pumps in 2050 are air-source heat pumps.

The **economic potential** is assessed on the basis of the scenarios produced by Fraunhofer ISE (Sterchele et al. 2020) and Gerhardt et al. (2019). Consideration is also given to Purr et al. (2019). **Sterchele et al. (2020)** calculated the cost-optimised shares of heat generators for four different scenarios: ‘Reference’, ‘Inertia’, ‘Lack of acceptance’ and ‘Sufficiency’. All scenarios achieve a CO_2 reduction of 95% by 2050 compared to 1990. The shares of the individual heat-generating technologies can be regarded as their economic potential under the specific constraints of the relevant scenario. The potential of all heat pump types for 2030 accordingly lies within a spectrum extending from 18.5 to 93 TWh. The spectrum of values for 2050 extends from 109 to 310 TWh. A figure for air-source heat pumps as a share of overall potential for all heat pump types can only be specified on the basis of a further approximation. Sterchele et al. (2020) provide figures for air-source and ground-source heat pumps as a share of the total number of heating systems. Air-source heat pumps account for a share of 1.5-11.6% of all heat sources in 2030. The share of air-source heat pumps increases to 18.5-48.5% in 2050. The total potential for heat pumps is broken down between the two different sources (‘air’ and ‘ground’) on the basis of these shares. This breakdown is an approximation which presupposes – for the sake of simplicity – that the share of heat generators is proportionate to the quantitative share of heat. The **economic potential** of air-source heat pumps is therefore 11-85 TWh in 2030 and 96-279 TWh in 2050. The scenarios underlying the studies by Jochum et al. (2017) and Sterchele et al. (2020) reach very different conclusions regarding changes in consumption in buildings. The economic and technical potentials are therefore not directly comparable with each other. Since the concept of an economic potential being larger than a technical potential is only comprehensible against the backdrop of the different scenarios and is thus difficult to communicate, the upper limit for economic potential is reduced in this report so that it is identical to the technical potential.

Gerhardt et al. (2019) investigated two different scenarios for changes in building efficiency, and carried out calculations both with and without the use of biomass in the buildings sector. This also results in four scenarios, each of which achieves a CO_2 reduction of 95%. The cost-optimised heating market for these scenarios was identified using the SCOPE optimisation model. Air-source heat pumps account for 32-59% of the heat produced in 2050. This corresponds to a quantity of supplied heat of 162.7-227.3 TWh. An economic potential of air-source heat pumps of 32.7-39.3 TWh is calculated for 2030. The extreme values from

both of the aforementioned studies are incorporated into the final result in order to reflect the uncertainty that surrounds calculations of the economic potential.
Purr et al. (2019) did not apply an economic optimisation model to heat generators with a view to minimising costs for final users. The study shows the distribution of air-source heat pumps for five scenarios, however, taking into account energy and resource efficiency. They contribute 15-53 TWh to the supply of heat in 2030, and 66-125 TWh in 2050.

Table 9 illustrates the potentials of air-source heat pumps. A significant reduction in useful heat consumption also decreases the absolute heat pump potential. This is revealed by a direct comparison of the technical potentials specified for 2030 and 2050. The improved options for integrating heat pumps into more efficient buildings have already been taken into account in these potentials. Coverage by heat pumps increases in relative terms, however.

When determining economic potentials, an obligation to reduce greenhouse gas emissions by 95% in 2050 compared to 1990 was assumed. The energy prices of conventional technologies (natural gas and oil) are set to remain constant until 2050. In the case of electric heat pumps using outdoor air as a source of heat, a decreasing trend is assumed for investment costs (from EUR 900/kW$_{th}$ in 2020 to EUR 640/kW$_{th}$ in 2050). Detailed assumptions about costs and energy quantities are provided in the annex to the study by Sterchele et al. (2020).

Table 9: Overview of results of potential analysis for decentralised air/water-source heat pumps

Energy source (TWh/a)	Technical demand potential		Economic potential	
	2030	2050	2030	2050
Decentralised ambient air – heat pumps	**260-267**	**176-242**	**11-85**	**66-242**

6.2 Centralised ambient air

6.2.1 Introduction

When heat is produced from ambient air, the latter constitutes a location-independent source of heat that can be used with minimal technical effort by means of air-source heat pumps (Born et al. 2017). It can be used not only on a decentralised basis, but also on a centralised basis. High-capacity air/water-source heat pumps extract heat from the ambient air for this purpose, heat it to a higher temperature and feed it into the heating networks. Both the technical considerations and the distribution of high-capacity heat pumps of this kind are examined below. Heating network temperatures and their impact on the ease of integration of centralised air heat pumps are also investigated.

Technical aspects

The term ‘high-capacity heat pumps’ can be understood to include heat pumps with a compact design and with a thermal output of over 200 kW per device, installed in a cascading arrangement in certain cases. Technologies such as reciprocating piston compressors are used to achieve higher efficiencies and high flow temperatures in this connection

(Brechbühler et al. 2019). The technical limits of air/water-source heat pumps are determined by the chosen refrigerant, among other things. Depending on the choice of refrigerant, usable outdoor temperatures of down to -20 °C and flow temperatures of up to 70 °C can be achieved. The compressors and ventilators of heat pumps emit noise during operation, at a level of approximately 30-55 dB(A) at a distance of 10 m (Brechbühler et al. 2019).

Distribution in Germany and Europe

High-capacity heat pumps with outputs of several megawatts have been available on the market for several years. In 2017, a study by the Bochum University of Applied Sciences (Born et al. 2017) investigated the market for high-capacity heat pumps in Germany. On the basis of the available data, the authors assume that the number of high-capacity heat pumps in the whole of Germany in late 2016 was around 100, with a comparatively low average output of 300 kW. This study also highlights the high possible potentials of high-capacity heat pumps, based on the transformation of district heating networks into networks with lower flow temperatures. When used in low-calorific heating networks, heat pump technologies can make a particularly efficient contribution to the supply of heat.

The use of high-capacity heat pumps for the centralised supply of heat in heating networks is much more widespread in other European countries than in Germany. In Denmark alone, over 25 high-capacity heat pumps were installed between 2008 and 2018, with further increases to be expected in the years to come. These projects differ in terms of size, heat source and configuration. In 2017, there were 149 high-capacity heat pumps with an output of over one megawatt installed across Europe. High-capacity heat pumps with an output of over one megawatt have been installed at an increasing rate since the turn of the millennium, particularly in Denmark, Finland, France, Norway, Italy and Switzerland (Pieper et al. 2018).

In an analysis of the role of high-capacity heat pumps for energy systems, using Denmark as an example, Dominković (2015) from the Technical University of Denmark concluded that high-capacity heat pumps not only reduce the costs of the energy system, but also lead to lower CO_2 emissions, fuel savings and a lower likelihood of surplus electricity production; a larger number of high-capacity heat pumps should therefore be integrated into the Danish energy system in the near future.

System temperatures

Low system temperatures in heating networks are a vital factor in the decarbonisation of heating networks by means of local ambient heat potentials. This is the only way that ambient heat sources such as ambient air can be incorporated efficiently (Gerhardt et al. 2017). Reservations are still expressed by many regarding the level of efficiency of heat pumps from an energy-related or economic perspective. On the other hand, a wide range of possible uses exists, particularly at low flow temperatures, and bivalent solutions with peak load production may even be an option for non-renovated buildings with higher flow temperatures (Gerhardt et al. 2017).

Deutsch et al. (2019) also conclude that high system temperatures constitute a barrier to the integration of local renewable energies. Networks installed more recently that are operated at flow temperatures of between 60-90 °C and low-ex networks or cold heat networks with much lower flow temperatures again offer significantly better opportunities for the integration of local ambient heat potentials. The authors also point out that the reduction of temperatures in all existing networks is typically associated with a drop in heat load, and therefore a drop in heat sales. Renovation measures on the customer side may therefore diminish the profits to be earned by heating network operators.

The German Association of Energy and Water Industries [Bundesverband der Energie- und Wasserwirtschaft, BDEW] also emphasises that high flow temperatures in existing networks represent a barrier to the integration of centralised heat pumps. The high-capacity heat pumps currently in widespread use achieve flow temperatures of up to approximately 80 °C; in existing district heating networks, however, flow temperatures of over 100 °C are frequently required, particularly during the winter months. The lower flow temperatures mean that the summertime use of high-capacity heat pumps can be considered. Further options for use include the establishment of secondary networks that are separate from the primary network and that operate at lower temperatures. The use of district heating return flow as a source of heat for a secondary network supplied via heat pumps is a special variant of these systems. In this instance, synergies are leveraged through cooling of the return flow from the primary network, which may increase the level of efficiency of the primary network. Additional heating using a boiler system is also an option (Petersen et al. 2017).

In the Danish town of Sig, a centralised air/water-source heat pump with an output of around one megawatt was put into operation in 2017. Until 2013, the local energy supplier (Sig Varmeværk) used only natural gas to produce district heating. A total of 3 500 m² of solar thermal was installed in 2013, and the air/water-source heat pump was added in 2017. The heating network supplies around 300 customers, with total heat sales of around 6.5 GWh. In the long term, it is anticipated that the heat pump will cover approximately 46% of heat demand. The network achieves a coefficient of performance (COP) of around 3.5 and flow temperatures of over 60 °C. The flow temperature in the network is temporarily reduced to 60 °C for the purpose of integrating the heat pump (Elmertoft 2019).

Figure 16: 1-MW air-source heat pump with air as the heat source, in Slagslund, Denmark (Courtesy of PlanEnergi)

6.2.2 Total heating and cooling potential and classification

A simulation-based approach was used to calculate the technical and economic heat potentials.

The unlimited availability of the resource ‘ambient air’ as a source of ambient heat means that there is no restriction on the supply of heat. An upper limit is however imposed on the demand for heat, which is characterised by the quantities of heat sold in heating networks in the years to be investigated (heating network potential). The first step therefore involves estimating the heating network potential for the various reference years. Subsequent steps involve calculating the share of the heating network potential that can be covered by centralised air/water-source heat pumps on the basis of assumptions and simulations.

The upper limit of the technical potential was determined on the basis of the quantity of heat that can be discharged into potential heating networks, which in turn was calculated using the open source mapping and planning tool Hotmaps[1]. On the basis of a heat density map with high geographical resolution (100 m x 100 m grid cells) for Germany, the limit value for 2016 was calculated on the basis of a minimum heat density of 150 MWh/a per hectare and a minimum heat demand of 10 GWh/a per heating network. **This results in a technical heating network potential of 544 TWh for Germany.**

On the basis of the scenarios outlined by Sterchele et al. (2020), the economic heating potential is calculated using assumed heat sales in heating networks of 110 TWh (2020), 140 TWh (2030) and 180 TWh (2050). These scenarios incorporate economic optimisation of the overall energy system. The potentials relate to the district heating used for space heating and hot water in all sectors.

A simulation is initially run to calculate the share of these heating network potentials that can be covered using centralised air-source heat pumps. The energyPRO software is used to generate a heating load profile to the nearest hour for each of the three locations (Hamburg, Berlin and Munich). The outdoor temperature series for these locations are selected for the purpose of mapping potential discrepancies within Germany. It follows that these are not sample networks that are used for calculation purposes; instead, they are merely used for the purpose of considering different climatic conditions within Germany.

This load profile is relative and can be scaled on the basis of total heat sales. Heating limit temperatures of 12 °C (new builds) and 15 °C (existing buildings) are used as a basis for this purpose, as well as a proportion of 10 % of new builds in 2020, 15 % in 2030 and 25 % in 2050.[2] The heating load profile generated in this way is compared against the outdoor temperature. If these temperatures are above the assumed limit temperature for the technically achievable or economically feasible deployment of air-source heat pumps, it is assumed that these hours can be covered by air-source heat pumps. The background to this methodology is that the coefficient of performance (COP) of an air-source heat pump, which specifies how much heat is supplied per unit of electricity used, drops in step with reductions in the outdoor temperature. This means that the level of economic and energy efficiency also decreases as the outdoor temperature drops. The calculations are based on the following significant operating limit temperatures for air-source heat pumps: -5 °C, 0 °C and 5 °C.

The quantitative share of heat in heating networks (calculated using the above methodology) that can be covered by air-source heat pumps is shown for the different operating limit temperatures at which the air heat pumps are used in the three locations chosen as examples and for the various reference years in Table 10. It can be seen that the potentials are only influenced to a limited extent by location. The key influencing factor is the outdoor temperature at which the air-source heat pump is operated (operating limit temperature). The mean value for the three locations is used for further calculations of potential.

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[1] https://www.hotmaps.hevs.ch/map

[2] Own assumptions, based on the Report on Buildings by the German Energy Agency **Invalid source specified.**, with an annual new-build rate of 0.5%, and empirical values from reference projects

The problem of operating limit temperatures is partly of a technical nature (the limit temperature down to which operation is technically possible), and partly of an economic nature. Since the efficiency of the heat pump drops at low temperatures, the specific electricity input increases as the outdoor temperature decreases. **The technical potential is calculated below on the basis of information from various manufacturers, assuming an operating limit temperature ($T_{\text{technical operating limit}}$) of -5 °C.** Viessmann also refers to high-capacity air-source heat pumps that are operated at an outdoor temperature of down to -5 °C and that achieve a flow temperature of 45 °C. Similarly, CTA AG refers to reference projects with usable outdoor temperatures of between -5 °C and -7 °C at a COP of between 2.5 and 3, and flow temperatures of around 40 °C (Brechbühler & Müller, 2019). If a higher flow temperature is to be achieved (70 °C, for example), a COP of 2.5 corresponds to usage at an outdoor temperature of no lower than 5 °C (in a reference project carried out by CTA AG (Brechbühler et al. 2019)). The calculations of potential carried out in this connection are not based on any assumptions concerning network temperatures. Possible future changes in network temperatures (i.e. increasingly low temperatures) are accordingly ignored.

An operating limit temperature for centralised air-source heat pump ($T_{\text{economic operating limit}}$) of 5 °C is assumed for the **economic potential**. Systems may ice up at low outdoor temperatures, necessitating active defrosting of the heat exchangers; additional heat exchanger capacity is therefore required during these periods for the same heat yield. These additional technical requirements lead to significant added costs, and so a limit temperature of 5 °C is assumed when estimating the economic potential.

Table 10: Share of heating networks that can be covered by air-source heat pumps at different heat pump operating limit temperatures and for different locations, with mean value. The differences between the individual years (2020, 2030 and 2050) result from changes in the structure of the building stock (ratio of new builds to existing buildings). (Source: own calculations)

Location/limit temperature of air-source heat pumps	**Share of heat that can be covered by air-source heat pumps**		
Hamburg	**2020**	**2030**	**2050**
5 °C	54%	54%	55%
0 °C	84%	84%	84%
-5 °C	98%	98%	98%
Berlin	**2020**	**2030**	**2050**
5 °C	51%	51%	52%
0 °C	80%	80%	80%
-5 °C	96%	96%	96%
Munich	**2020**	**2030**	**2050**
5 °C	51%	51%	52%
0 °C	81%	81%	82%
-5 °C	98%	98%	98%
MEAN	**2020**	**2030**	**2050**
5 °C ($T_{\text{economic operating limit}}$)	**52%**	**52%**	**53%**
0 °C	82%	82%	82%
–5 °C ($T_{\text{technical operating limit}}$)	**98%**	**98%**	**98%**

This approach takes into account the ambient temperatures and operating limits of the air-source heat pumps, but ignores other influencing factors. For example, any resulting limitations on permit eligibility linked to noise emissions are not taken into account, and the same is true for changes in climatic conditions over the next 30 years. The extent to which existing heating networks are suitable for air-source heat pumps on the basis of their network parameters, in particular their flow temperature, is also not examined in closer detail[1]. It is assumed that future heating networks will in any case evolve towards lower system temperatures. Another factor that is not taken into account is the space required for installation and the heat exchangers. It is assumed that the required heat exchanger footprint of approximately 150 m² per megawatt of installed output is available on buildings or in open spaces. Consideration must also be given to the fact that the potential of air-source heat pumps may compete with other RES technologies such as solar heat production, since both technologies deliver particularly high yields in the summer.

Given that the effects described cannot be quantified individually and in detail within the framework of this report, the potentials for 2020 are offset by a discount factor of 50%, thereby placing a lower limit on the range of potentials. In view of the likelihood of positive developments in the parameters, in particular network temperatures but also any further technological advances, the calculations **for 2030 and 2050** are carried out using **discount factors of 40% (2030) and 20%** (2050). After the application of discount factors, the potential ranges therefore equate to 60-100% (2030; discount factor of 40%) or 80-100% (2050; discount factor of 20 %) of the calculated potentials.

This results in the potentials shown in Table 11 below.

Table 11: Overview of results of potential analysis for centralised ambient air. Details of heat produced (final energy).

Energy source (TWh/a)	Technical demand potential			Economic potential		
	2020	**2030**	**2050**	**2020**	**2030**	**2050**
Centralised ambient air	**265-530**	**318-531**	**425-531**	**28-57**	**44-73**	**76-95**

Reversible air/water-source heat pumps represent a good way of combining the supply of heating and cooling. They can be operated either as heat pumps or – by reversing their operation – as cooling pumps. If they are operated in cooling mode, the waste heat is discharged via the heat exchangers. It should be noted that, even in the warmer months of the year, the air-source heat pumps are still used to produce heat (e.g. for domestic hot water); this may mean that only a portion of the output of the reversible heat pumps is available for the production of cooling in summer. Particularly in settings with a constant demand for cooling, for example food-processing operations or hospitals, reversible air-source heat pumps can still be used to produce cooling during the months of the year when outdoor temperatures are too cold for them to be used for heat production purposes.

Reversible heat pumps have not yet conquered a significant share of the market in Germany. They are primarily used in non-residential buildings such as offices and industrial buildings,

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[1] See also the comments on system temperatures in the preceding section.

where space cooling with parallel use of the resulting waste heat for the supply of heating using a heat pump can result in particularly high system efficiencies (Born et al. 2017).

6.3 Surface waters

6.3.1 Introduction

Enormous amounts of heat are stored in surface waters such as rivers, lakes and seas. Water has a high thermal capacity, and temperature variations in surface waters are also more gradual and less pronounced than the daily and seasonal fluctuations in air temperatures. The heat absorbed in the summer is stored in bodies of water right into the winter months, meaning that the temperature of a river or lake or the temperature of seawater is often higher than the outdoor temperature on cold winter days.

The thermal use of surface waters capitalises on these characteristics. The process involves removing low-caloric heat from water and raising it to a higher temperature using a water/water-source heat pump. Not only heating, but also cooling can be produced using water/water-source heat pumps. The pumps are designed or operated reversibly for this purpose, and the heat to be dissipated is discharged to the surface waters. The extraction of heat from waters when the pumps are in heating mode is typically less harmful from an ecological perspective and more straightforward from a permit-related perspective than the discharge of heat into the waters when the heat pumps are operated in cooling mode.

A distinction can be made between two types of surface water-source heat pumps with regard to the design of these systems. In open systems, water is extracted from the surface water and routed through the heat exchanger. In closed systems, the heat exchanger is located directly in the water. One advantage of closed systems from a permit-related perspective is that no water is extracted, which means that the water is not deemed to be ‘used’ within the meaning of Section 9 of the Water Resources Act [Wasserhaushaltgesetz, WHG] and a permit can therefore be obtained more easily. Open systems are also more structurally complex in many cases, since the water must be extracted through a pipe and (for example) cleaned in a filter before being routed into the heat exchanger. Intermediate circuits can be integrated into both open and closed systems in order to prevent the accumulation of ice on the heat exchangers and to facilitate ecological water pollution control (Schwinghammer 2012).

Although water/water-source heat pumps (primarily those using ambient heat from lakes) are already extremely popular in other European countries such as Switzerland, thereby demonstrating the functional and economic viability of these systems, very few have been installed in Germany. A study on lake-source heat pumps carried out in 2017 revealed that only 15 of these heat pumps are in operation in Germany (Kammer 2017). A survey relating to heat pumps in watercourses revealed that as few as 10 river-source heat pumps are in operation across Germany (Abel 2018). Almost no heat pumps that use seawater as a source of heat have been installed in Germany to date. Given the ease of access to the North Sea and Baltic Sea coasts and the increasing demand for heat in coastal regions, however, the thermal use of seawater is just as valid an option as the use of watercourses and lakes.

The reasons for the limited popularity of this technology in Germany are many and varied. Limiting factors on the thermal use of surface waters include firstly the distance between the heat sink and the source of heat (the water) and the absence of an adequately high heat density or population density in close proximity to the source of heat. Owing to the high investment costs involved, making surface waters accessible is often only worthwhile if a correspondingly large amount of heat can be sold, i.e. if the heat can be fed into local or district heating networks (Kammer 2017). Factors that affect the economic viability of the system include not only the distance to the heat source, but also the difference in height between the customers and the heat source.

Factors impeding the spread of this technology in Germany include not only the requirement for adequate local heat demand, which is necessary in order to achieve economically viable thermal use of surface waters as close as possible to the water, but also certain provisions of water law, nature conservation law and environmental law, as well as a lack of familiarity with the technology (Kammer 2017). The efficiency of surface water-source heat pumps also increases if the flow temperature to be produced is lower. Once again – as was seen for centralised air-source heat pumps – reducing the temperature of heating networks makes it easier to integrate these systems into the heating supply.

The Värtan Ropsten facility in Sweden is a best practice example that has demonstrated for decades that the operation of seawater-source heat pumps is practically and economically feasible and produces a high output all year round; six heat pump units are connected to form the world’s largest seawater-source heat pump facility with a total capacity of 180 MW. With a COP of 3.75, the facility produces heat at a flow temperature of 80 °C for Stockholm’s district heating network. In the summer months the seawater is extracted at the surface of the water, while in the winter months water is taken from a depth of 15 m at a constant temperature of 3 °C (Friotherm 2017).

6.3.2 Total heating and cooling potential and classification

Table 13 shows the total heating potential of surface waters. The total potential comprises the potential from the individual water types (rivers, lakes and seas).

A study by the Fraunhofer IEE calculates the potentials of river-source heat pumps and lake-source heat pumps in Germany for 2030 and 2050 (Gerhardt et al. 2019). In the study, the technical demand potential is only calculated and specified separately for lakes; joint technical and economic potentials are calculated for both lakes and watercourses. A total of 33 rivers with a minimum discharge of 40 m^3/s[1] are compared from a geographical perspective against the heating demand of the population in close proximity to the rivers for the purpose of calculating the potential of river-source heat pumps. The maximum permitted distance between the heat sink and the midstream of the river is set at 2 km. This results in a potential of 50 TWh for 2030 with a COP of 2.2 and approximately 5 000 hours of full utilisation, as well as potentials of 37.5 TWh (‘Trend’ scenario; COP 3.1) or 27.6 TWh (‘Ambitious’ scenario; COP 3.3) in 2050. The different ranges are a consequence of the two different scenarios used as a basis for the study. The ‘Trend’ scenario assumes a higher final energy consumption, and the potentials calculated on this basis are accordingly higher than those calculated on the basis of the ‘Ambitious’ scenario.

The thermal potential of the North Sea and Baltic Sea in Germany has not been investigated in the literature to date, and so this report will apply a generic approach for the purpose of estimating this potential. The methodology underlying the approach involves the spatial and temporal overlaying of heating demand in coastal regions with the heating supply of potential seawater-source heat pumps.

Analyses using the GIS-based online tool Hotmaps and energy system simulations using energyPRO are carried out for this purpose. Figure 17 provides an overview of the procedure.

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[1] The Spree is also included in the analysis, even though it does not meet the minimum discharge requirement.

The assumptions concerning the parameters for building stock composition (new builds/existing buildings) and heating limit temperatures are identical to those used as a basis for calculating the potential of centralised air-source heat pumps (Section 6.2.2).

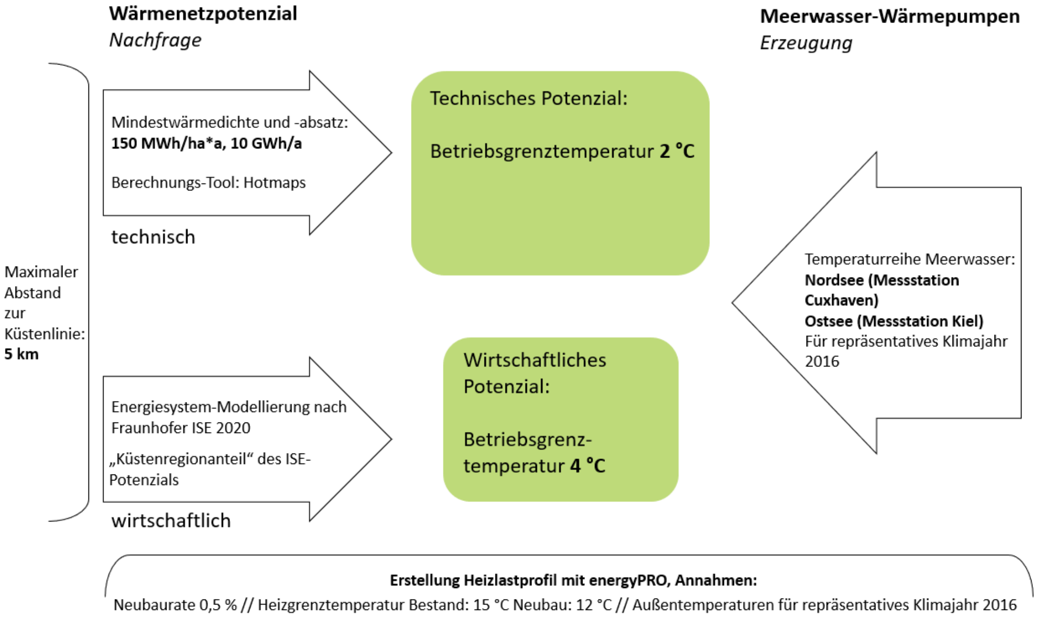

Figure 17: Overview of the methodology followed to calculate the potential of seawater-source heat pumps. (Source: own illustration)

Wärmenetzpotenzial	Heating network potential
Nachfrage	Demand
Meerwasser-Wämepumpen	Seawater-source heat pumps
Erzeugung	Production
Maximaler Abstand zur Küstenlinie: 5 km	Maximum distance to coastline: 5 km
Mindestwärmedichte und – absatz: 150 MWh/ha*a, 10 GWh/a	Minimum heat density and sales: 150 MWh/ha*a, 10 GWh/a
Berechnungs-Tool: Hotmaps	Calculation tool: Hotmaps
technisch	technical
Technisches Potenzial: Betriebsgrenztemperatur 2 °C	Technical potential: Operating limit temperature 2 °C
Energiesystem-Modellierung nach Fraunhofer ISE 2020	Energy system modelling on the basis of Fraunhofer ISE 2020
„Küstenregionanteil" des ISE-Potenzials	'Coastal region share' of the ISE potential
wirtschaftlich	economic
Wirtschaftliches Potenzial: Betriebsgrenztemperatur 4 °C	Economic potential: Operating limit temperature 4 °C
Temperaturreihe Meerwasser: Nordsee (Messstation Cuxhaven) Ostsee (Messstation Kiel)	Temperature series for seawater: North Sea (Cuxhaven measuring station) Baltic Sea (Kiel measuring station)
Für repräsentatives Klimajahr 2016	For representative climate year 2016
Erstellung Heizlastprofil mit energyPRO, Annahmen:	Generation of heating load profile with energyPRO, assumptions:
Neubaurate 0,5 % // Heizgrenztemperatur Bestand: 15 °C Neubau: 12 °C // Außentemperaturen für repräentatives Klimajahr 2016	New-build rate 0.5%//heating limit temperature for existing buildings: 15 °C, for new builds:

	12 °C//outdoor temperatures for representative climate year 2016

Seawater temperatures for the North Sea (Cuxhaven measuring station) and Baltic Sea (Kiel measuring station) are compared against the operating limit temperatures of seawater-source heat pumps in order to calculate the potential hours of full utilisation and (as a result) the share of heating network potential that could be covered.

By way of analogy to the calculation of potential for centralised air-source heat pumps, the technical heating network potential is calculated on the basis of a fixed minimum heating density of 150 MWh/ha per annum and minimum sales in a contiguous heating network region of 10 GWh/a, using Hotmaps.[1] Potential heating networks that are located at a maximum distance of 5 km from the North Sea or Baltic Sea coasts are included. The **technical heating network potentials** calculated using this method **are 3.3 TWh (North Sea) and 7.1 TWh (Baltic Sea); the total technical heating network potential in Germany's near-coast regions is therefore 10.4 TWh per annum.**

By way of analogy to the procedure followed when analysing the potential of centralised air-source heat pumps, the economic heating network potential is calculated on the basis of the modelling results for the energy industry that emerged from a recent study by Fraunhofer ISE (Sterchele et al., 2020).

For the purpose of calculating the share of economic heating network potential in near-coast regions, the potential calculated in this study is reduced to the share of the potential within 5 km of the coast. For the sake of simplicity, it is assumed that the number of people living in near-coast regions as a proportion of the total population corresponds to the share of final energy consumption. The **economic heating potentials** calculated in this way **are 1 117 GWh (2030) and 1 436 GWh (2050) for the North Sea and 2 148 GWh (2030) and 2 762 GWh (2050) for the Baltic Sea.**

From a technical perspective, seawater at a temperature of 0 °C can be used as a source of heat for certain vacuum liquid ice heat pumps that work at the triple point of water. Yet the seawater-source heat pumps that are most commonly used today have technical operating limit temperatures of around 2 °C. The technical limit temperature ($T_{\text{technical operating limit}}$) is therefore specified as 2 °C for the purposes of this analysis.

A seawater temperature ($T_{\text{economic operating limit}}$) of 4 °C is specified as an operating limit temperature for economically viable operations. It is possible to operate the heat pumps at lower temperatures, but the manufacturer states that output drops significantly below 4 °C.

This results in the following shares of heating network potential that can be covered at the different limit temperatures:

Table 12: Share of heating networks that can be covered by seawater-source heat pumps at different heat pump operating limit temperatures In the North Sea and Baltic Sea. The differences between the individual years (2020, 2030 and 2050) result from changes in the structure of the building stock (ratio of new builds to existing buildings). (Source: own calculations)

Location/ limit temperature	Share of heat that can be covered by heat pumps	Heating network

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[1] https://www.hotmaps.hevs.ch/map

seawater-source heat pump				**potentials [TWh]**	
North Sea	**2020**	**2030**	**2050**	**2030**	**2050**
4 °C ($T_{\text{economic operating limit}}$)	**89%**	**89%**	**90%**	**1 117**	**1 436**
2 °C ($_{\text{technical operating limit}}$)	**99%**	**99%**	**99%**	**3 300**	**3 300**
0 °C	100%	100%	100%		
Baltic Sea	**2020**	**2030**	**2050**		
4 °C ($T_{\text{economic operating limit}}$)	**72%**	**72%**	**73%**	**2 148**	**2 762**
2 °C ($_{\text{technical operating limit}}$)	**97%**	**97%**	**98%**	**7 100**	**7 100**
0 °C	100%	100%	100%		

This approach takes into account the seawater temperatures and operating limits of the seawater-source heat pumps, but ignores other influencing factors. The effects of limited eligibility for permits as a result of restrictions under water law, environmental law or nature conservation law cannot be quantified in these studies, and the same is true for changes in climatic conditions over the next 30 years. It is also impossible to quantify the extent to which existing heating networks are suitable for air-source heat pumps on the basis of their network parameters, in particular their flow temperature. It is assumed that future heating networks will in any case evolve towards lower system temperatures.

In order to take account of the aforesaid factors, discount factors are applied to the potentials calculated for seawater-source heat pumps in Germany on the basis of the method described above. The discount factors for thermal potentials from surface water are defined using a procedure similar to that followed for potentials from the centralised use of ambient air using heat pumps. Discount factors of 40% and 20% are included in the calculations for 2030 and 2050 respectively, resulting in the definition of potential ranges of 60-100% (2030) and 80-100% (2050) of the calculated potentials.

Table 13: Overview of results of potential analysis for surface waters (rivers, lakes and seas) (final energy).

Energy source (TWh/a)	**Technical potential**		**Economic potential**	
	2030	**2050**	**2030**	**2050**
Surface waters of which:	**110-114**	**90-102**	**81-82**	**49-66**
Rivers (Gerhardt et al. 2019)	**50**	**28-38**	**50**	**28-38**
Lakes (Gerhardt et al. 2019)	**54**	**54**	**29**	**18-25**
Seas (North Sea/Baltic Sea)	**6-10**	**8-10**	**2-3**	**3**

6.4 Waste water

6.4.1 Introduction

The advantage of using municipal waste water as a source of heat for heat pumps is that – by way of contrast to ambient air – the temperatures are always similarly high over the course of the year, since waste water temperatures vary between 10 °C and 15 °C even during the heating period (DWA, 2009). Furthermore, spatial synergies often exist between the availability of waste water and heating demand.

Waste water can be used for energy-related purposes in a number of different ways. Although the geographical distance to possible heat sinks cannot be altered when untreated waste water is used upstream of a waste water treatment plant, care should be taken when making the source accessible to avoid excess cooling of the waste water[1], which might have an adverse impact on processes in the waste water treatment plant. The waste water can be used directly in the waste water treatment plant; alternatively, the treated waste water can be used for energy-related purposes after passing through the plant. The energy-related use of waste water is however complicated by the fact that waste water treatment plants are typically operated outside built-up areas, which increases the access-related costs of incorporating them into district heating networks.

Heat exchangers are necessary to make waste water accessible as a source of heat. They can be installed either directly in the sewer or as bypass heat exchangers. Sewer-based heat exchangers are already available as pre-manufactured components, and can also be retrofitted in sewers. A nominal sewer size of at least DN 400 is required in this case, however, as well as any retrofitting interventions required. Bypass heat exchangers remove part of the flow of waste water and can be used without intervention in the sewer itself. Installing the heat exchanger outside the sewer means that more space is required, however, and the initial investments are also higher (Christ & Mitsdoerffer, 2008).

The energy-related use of waste water by means of heat pumps generally takes place on a bivalent basis. Heat pumps are often combined with cogeneration units or other technologies to achieve improved annual coefficients of performance at peak load, thereby reducing heat production costs.

The energy-related use of waste water in buildings can be achieved through integration into the building's heating plant or through integration into heating networks (Fritz & Pehnt, 2018). Different concepts exist for the latter, centralised option: after being fed into cold local heating networks operating at temperatures of 8-20 °C, the energy from waste water is brought to the necessary temperature on a decentralised basis using small-capacity heat pumps in the individual buildings. Incorporation into heating networks operated at higher temperatures is associated with larger network losses, but advantages of this approach include the smaller installation space and lower investment costs for a larger heating plant.

Figure 18 shows a schematic of the energy-related use of waste water in heating networks, directly from the sewer and upstream of the waste water treatment plant.

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[1] Projects and preliminary studies that have already been implemented reveal that cooling of up to 4 K is possible without an adverse impact on the operating principle of the waste water treatment plants. For further details, see (Fritz & Pehnt, 2018), page 8.

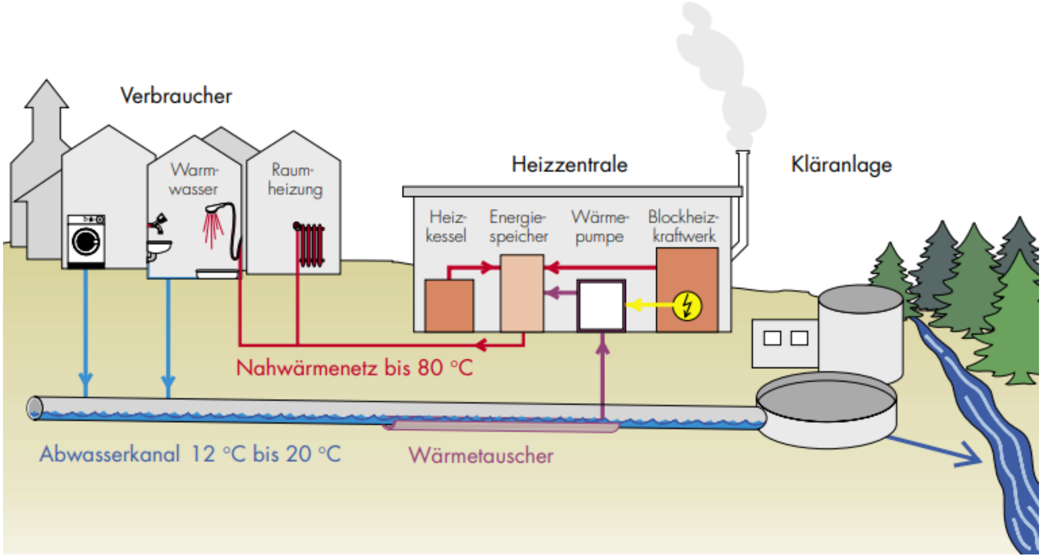

Figure 18: Principle of obtaining heat from waste water using heat exchangers placed directly in the sewer, bivalent operation of heat pumps in the heating plant and feed-in to a warm local heating network. (Source: Müller, Schmid, & Kobel, 2005)

Verbraucher	Consumer
Warmwasser	Hot water
Raumheizung	Space heating
Heizzentrale	Heating plant
Heizkessel	Boiler
Energiespeicher	Energy storage unit
Wärmepumpe	Heat pump
Blockheizkraftwerk	Cogeneration plant
Kläranlage	Waste water treatment plant
Nahwärmenetz bis 80 °C	Local heating network up to 80 °C
Abwasserkanal 12 °C bis 20 °C	Sewer 12 °C to 20 °C
Wärmetauscher	Heat exchanger

Waste water can be used for energy-related purposes through reversible operation of heat pumps, for example; if the waste water is at a sufficiently low temperature, it can also be used directly for cooling purposes.

Municipal heat sources have been used in Germany for energy-related purposes since 1982 (Butz & Müller, 2010). According to one manufacturer of sewer-based heat exchangers, approximately 90 systems had been installed by January 2020 (UHRIG, 2020). Some of these systems are also used for cooling purposes. The corresponding installed output for heating varies between 12 and 2 100 kW; the output for cooling varies between 95 and 1 000 kW.

Fritz & Pehnt, (2018) defined the influencing factors and conditions for the choice of location and technology. As well as the nominal sewer size and the waste water temperature required at the entry to the waste water treatment plant, other restricting factors that were identified include the flow rate in the sewer, the output at the consumer, the monthly fluctuations in consumption of domestic hot water and heating and the distance between the heat source and the heat sink.

The lower the temperatures in the heating networks, the higher the annual coefficients of performance for the heat pumps, and the higher the potential of accessible energy from waste water. Gerhardt et al. (2019) found a significant overlap between the potentials on the demand side for the use of energy downstream of the waste water treatment plants and the potential of river-source heat pumps.

The economic feasibility of using energy from waste water depends to a large extent on the energy policy framework conditions, since the purchase of electricity is subject to different taxes, levies and charges.

A local heating network with a heat pump utilising energy from waste water was implemented in Bretten (Baden-Württemberg) as long ago as 2009. The network supplies heat to several residential buildings, a sports hall and a secondary school. Around 10 years later, a system was installed in Stuttgart-Neckarpark (a new-build development) that supplies over 450 residential units, primarily on the basis of waste water. To guarantee that the energy from waste water can be used to the fullest possible extent even in summer, when heating demand is lower, two buffer tanks with a waste water volume of 115 m^3 were also installed[1].

6.4.2 Total heating and cooling potential and classification

Drawing on various studies, this section initially describes the technical and economic potentials for energy from waste water in Germany in 2030 and 2050, including both untreated waste water used in the sewer and treated waste water used downstream of the waste water treatment plant. Table 14 provides an overview of the range of potentials specified in the literature. The results for the energy-related use of waste water in the sewer and downstream of the waste water treatment plant are shown separately. It is evident that the potential from sewer-based systems – which are closer to the heat sinks – is higher than the potential from systems using treated waste water downstream of the waste water treatment plant. Increasing efficiency levels in the building stock mean that the potential in 2050 will be lower than that in 2030.

Details of the individual data sources are provided below as a basis for describing the assumptions underlying these sources that lead to the respective findings regarding potentials.

Table 14: Overview of the results of the potential analysis for energy from waste water

Energy source (TWh/a)	Technical potential		Economic potential	
	2030	2050	2030	2050
Energy from waste water of which:	36-46	24-38	5-7	16
Sewage system	20-30	13-26	5-7	16
Waste water treatment plants	16	11-12		

Fritz & Pehnt (2018) also develop an approach for the small-scale calculation of joint technical and economic potentials for energy from waste water. The proportion of human set-

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[1] https://www.stuttgart.de/pressemitteilungen/2019/september/waerme-aus-abwasser-zwei-puffer-speicher-im-neckarpark-sichern-versorgung.php

tlements located in a radius of 300 m or 1 000 m of waste water treatment plants is calculated on the basis of a heat atlas that is accurate to the nearest building (residential buildings and services sector). Taking into account a load profile and a maximum possible temperature difference of 4 K, a joint technical and economic potential of between 22 TWh and 33 TWh of useful energy is calculated for 2011 (3.2-4.9% of the useful heat demand for space heating and hot water in buildings); the potential drops to between 20 TWh and 30 TWh for 2030, which nevertheless corresponds to 3.4-5.2% of the useful heat demand[1]. The authors also contextualise their results against other previous potential studies, and conclude that a temperature difference of 14 K must be used as a basis for a technical potential of approximately 100 TWh, as specified in Ecke & Göke (2017). The authors believe that this may be possible in individual cases, but cannot easily be generalised, and probably exceeds the achievable potential.

Gerhardt et al. (2019) analyse the potential of waste water heat pumps in the sewer and after waste water treatment plants on the basis of two scenarios (‘Trend’ scenario and ‘Ambitious’ scenario). Their analysis of energy from the sewage system follows the example of Fritz & Pehnt (2018), based on the assumption that the waste water is initially used in the sewer as a result of spatial proximity to the heat sinks, and that only the remaining thermal potential is allocated to uses after the waste water treatment plant. The analysis ascribes a higher output to the heat pumps, with use permitted only in urban areas with over 10 000 residents. The resulting joint technical and economic potential, based on a temperature difference of 4 K, is approximately 12 TWh for 2030 and between 8 TWh (‘Ambitious’ scenario) and 11 TWh (‘Trend’ scenario) for 2050[2]. The additional potential downstream of waste water treatment plants calculated on the basis of the above is specified as 16 TWh in 2030 and between 11 TWh (‘Ambitious’ scenario) and 12 TWh (‘Trend’ scenario) in 2050[3], based on a potential temperature difference of 6 K; owing to the longer connecting pipeline that is required, however, only towns or cities with over 20 000 residents qualify as heat sinks. The total potential for energy from waste water is therefore 28 TWh in 2030 and between 19 TWh and 23 TWh in 2050.

The approach followed by Fritz & Pehnt (2018) is adapted as follows in the following parallel project carried out by the German Environment Agency: ‘Analysis of the economic potential for efficient heating and cooling – contribution to the reporting obligation pursuant to Article 14 of and Annex VIII to the Energy Efficiency Directive’ (Ortner et al., ongoing): the heat demand for residential buildings and buildings in the services sector in 2018 (based on NECP Target Scenario 2) is used as a basis, and all heat consumers located within 1 km and with a heat density of at least 15 GWh/km^2 are identified as potential heat sinks. A estimate of 3.15 is used for the annual COP. The resulting technical potentials for 2018 are calculated as 31 TWh. The aforementioned project involves calculating economic potentials on the basis of a small-scale analysis of technical potentials. On the basis of the technical potential of energy from waste water and other renewable energy sources and waste heat, an analysis is carried out at municipal level from an economic perspective to determine the mix of energy sources resulting from a required RES share of 40% in the district heating mix, and to determine a similar mix of energy sources resulting from a required RES share of 100%. An additional evaluation reveals that the economic potential of energy from waste water is approximately 5-7 TWh with a required RES share of 40%, and approximately 16 TWh with a required RES share of 100%. The relevant economic potentials are used for the purpose of potential calculations on the basis of the assumption that the share of 40% corresponds to 2030 and the share of 100% corresponds to 2050.

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[1] COP of 4.5.

[2] COP of 2.9 in 2030 and 3.4-3.6 in 2040.

[3] COP of 2.25 in 2030 and 3.2 or 3.4 in 2040.

7 Analysis of the potential of geothermal energy

The following use cases are taken into account separately for the purpose of analysing potentials in the field of geothermal energy:

- use of deep geothermal energy in heating networks (see Section 7.1),
- use of near-surface geothermal energy in the building stock and in heating networks (see Section 7.2),
- use of energy from mine water (see Section 7.3).

7.1 Deep geothermal energy

7.1.1 Introduction

On average, the temperature of the subsoil increases by 30 K for every 1 000 m of vertical depth; even higher temperature gradients can be observed in certain locations. The advantage of using deep geothermal reservoirs (typically defined as reservoirs from a depth of >400 m) via a primary circuit of abstraction and reinjection boreholes with water as the heat transfer medium is that they constitute a source of energy that is capable of bearing a constant load and is also controllable. Nevertheless, their usefulness depends on a geographical overlap between the relevant reservoirs and a sufficiently high heat demand in order to refinance the comparatively high costs of making them accessible.

Use of deep geothermal energy in Germany to date has centred around hydrothermal reservoirs in three potential zones: the North German Basin, the Upper Rhine Plain and the South German Molasse Basin. Existing projects are heavily focused on the South German Molasse Basin in the Greater Munich area.

Existing hot water aquifers are typically made accessible using a doublet system (an extraction borehole and a reinjection borehole located at reservoir level several hundred metres away). Recent projects in the Greater Munich area have been designed to take advantage of favourable geological baseline conditions by using multiple deflected boreholes from a single drilling site, allowing higher outputs to be achieved in certain cases and effects of scale to be leveraged when reservoirs are made accessible. The energy contained in the extraction water can be used to generate electricity in ORC or Kalina systems provided that the temperature is high enough (>100 °C) and the extraction rate is fast enough. The direct use of heat via heat exchangers and feed-ins into heating networks is also possible at lower temperatures; this is dependent on the operating temperatures of the heating networks (Kaltschmitt 2014). It follows that low network temperatures are also beneficial from the perspective of making deep geothermal energy accessible in a more efficient and widespread fashion. In certain cases, upgrading options (heat pumps or waste heat) are used to boost temperatures. This means that geothermal resources can be used even if the thermal water temperature is below the heating network temperature, although the level of efficiency achieved in such cases is generally lower than in the case of direct use (Sandrock et al., 2020).

Key parameters for the efficiency of deep geothermal energy projects on the supply side include a temperature difference between the reservoir and the heat sink that is as wide as possible, and the attainable hot water extraction rate; the thermal output that can be achieved results from a combination of these two parameters. Not only system utilisation, but also drilling depth and above-ground transport distance have a major impact on heat production costs; owing to possible small-scale geological differences, these parameters exhibit a comparatively high level of variation, and mean that costly preliminary investigations or comprehensive risk mitigation are necessary.

A total of 346 MW_{th} of district heating production capacity from hydrothermal reservoirs was installed in Germany in 2018, spread across 38 systems, with the primary objective of supplying district heating with an annual production of 1 009 GWh_{th}. The mean geothermal output achieved per system was 12 MW_{th}; the median was slightly lower at 10 MW_{th}. Three projects achieved outputs of >25 MW (LIAG 2020, Figure 19).

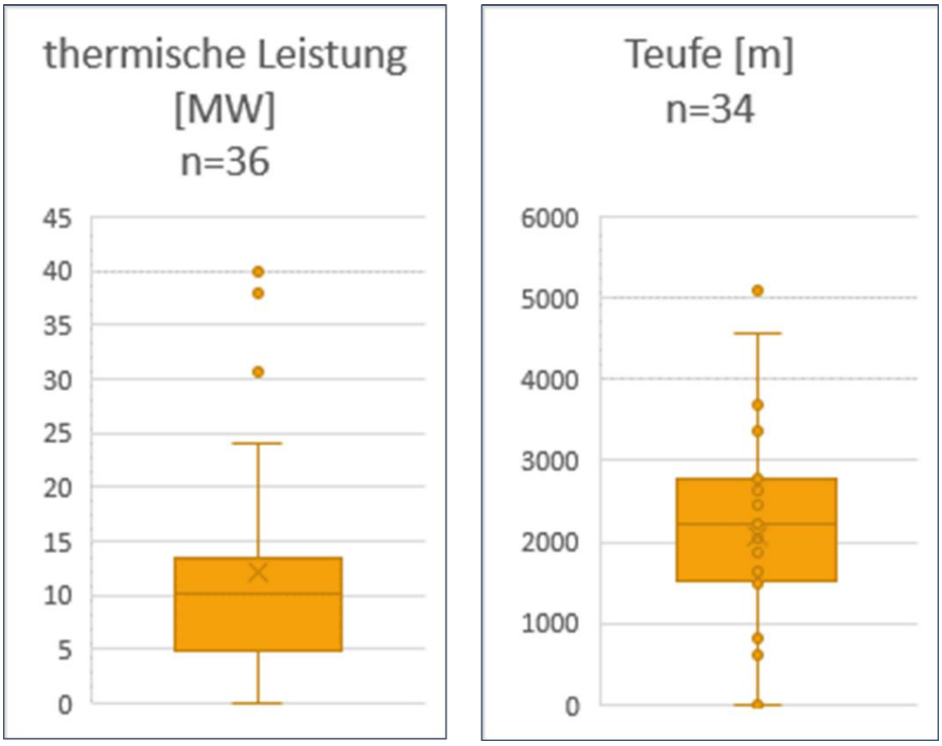

Figure 19: Distribution of geothermal output achieved (Ø 12 MW_{th}) and vertical drilling depth required, depth (Ø 2 200 m) of existing systems for the use of hydrothermal reservoirs >400 m in Germany in 2019. Own illustration based on Agemar, Weber and Schulz (2014), LIAG (2020).

thermische Leistung	thermal output
Teufe [m]	Depth [m]

Other regions in which the rocks are at an adequate temperature but where there is a lack of naturally occurring water as a transfer medium (petrothermal reservoirs) can be made accessible artificially by using water fed to fault zones at high pressure or by using artificial crevices. These procedures are more costly, however, and have not yet been tested extensively (Plenefisch et al., 2015). In the medium term, it can be assumed that hydrothermal reservoirs will predominantly be made accessible for the heating market (Bracke 2014).

As with the grid-bound use of centralised solar thermal energy, the use of deep geothermal reservoirs for cooling applications is mainly made possible via absorption cooling systems on the customer side of a heating network. Once again, the corresponding additional thermal output demand in the summer months may increase the quantity of economically useful energy from deep geothermal reservoirs by raising the number of hours of full utilisation.

7.1.2 Total heating and cooling potential and classification

This section opens with a discussion of the technical and economic potentials of deep geothermal energy in Germany. Table 15 provides an overview of the range of potentials, based on different assumptions concerning the maximum possible cooling of thermal water to a reinjection temperature T_2, but also concerning the future evolution of heating demand in the building stock. The use of lower reinjection temperatures not only increases the supply potentials in general terms by increasing the usable temperature difference between extraction and reinjection, but also means that new reservoirs with temperatures >=65° C are included in the assessment of potential.

Petrothermal potentials are not included among the potentials to be quantified as a priority within the framework of this study (potentials that are guaranteed to be usable by 2030). For the period up to 2050, additional potentials exist for the use of heat from petrothermal reservoirs; their technical and economic usefulness however depends on small-scale geological conditions and the advancement of technologies for making them accessible, and further research is needed in this area.

Table 15: Overview of results of potential analysis for deep geothermal energy The specified ranges are based on two scenarios for differing changes in energy demand for space heating and hot water in buildings.

Energy source (TWh/a)	**Technical demand potential**		**Economic potential**	
	2030	**2050**	**2030**	**2050**
Geothermal energy – deep geothermal, hydrothermal, reinjection temperature T_2 = 65 °C	**37-53**	**31-43**	**18-22**	**9-16**
Geothermal energy – deep geothermal, hydrothermal, reinjection temperature T_2 = 35 °C	**94-108**	**65-88**	**36-46**	**19-32**

In the case of **deep geothermal energy**, hydrothermal potentials in Germany were assessed on the basis of two scenarios involving reinjection temperature T_2[1]. Depending on the type of integration, the technical demand potentials are between 37 TWh and 108 TWh in 2030, dropping to between 31 TWh and 88 TWh in 2050 as a result of a reduction in heat demand. The economic potentials shown are therefore subject to an extremely high level of uncertainty. In addition to the general patchiness of the data available regarding investment costs, this is a result of the approach followed by Jochum et al. (2017), according to which economic viability is estimated on the basis of a standard limit value for specific heat production

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[1] The energy quantities are calculated on the basis of temperature differences, and the potentials shown do not include any heat valorisation using heat pumps or other technologies.

costs of hydrothermal deep geothermal energy of <EUR 75/MWh$_{th}$; substantial methodological simplifications are applied to obtain this figure (including standard hours of full utilisation of 3 000 h/a for geothermal heat power plants and the omission of temporally and geographically differentiated heat production costs).

The underlying methodological factors that result in the respective potential results are examined below.

A central source of data used when quantifying the supply potential of thermal energy in deep geothermal reservoirs in Germany is the deep geothermal information system GeotIS developed by the Leibniz Institute for Applied Geophysics (Agemar et al. 2014, LIAG 2020). GeotIS provides geographical data for the identification of hydrothermal reservoirs (adequate formation water available, circulation by means of extraction and reinjection) and petrothermal reservoirs (inadequate formation water available, injection of water as heat transfer medium and return transport) with details of the anticipated temperature. The underlying data are based not only on measurement data, but also on calculated subsoil models for the spatial interpolation of geological parameters, and are updated continuously. The fact that the hydrothermal potential zone in the South German Molasse Basin was reduced in 2019 on the basis of the geological findings published by Mraz (2019) must be taken into account when existing potential studies are evaluated (Figure 20). New geological findings may give rise to further changes to the supply potential in future.[1] In addition, the potential studies only take into account between one and seven aquifers per location (Schulz et al., 2013).

These data make it possible to assess the supply potential of deep geothermal energy, and to carry out a spatial intersection with possible heat sinks for the purpose of calculating the usable technical and economic potentials. The following parameters are specified on an exogenic basis for the analysis of potentials:

- usage restrictions in water protection areas or nature conservation areas,
- the minimum distances between extraction or reinjection boreholes with reference to the ground surface for the purpose of calculating a density model of extraction boreholes per km²,
- the fill rate that can be achieved [l/s] or the extractable mass flow rate of thermal water [kg/s], which can only be estimated roughly for larger-scale potential regions,
- the secondary temperatures used to calculate the achievable temperature difference (ΔT) between the flow and the return,
- the hours of full utilisation [h/a], for the purpose of calculating the useful energy quantity over the course of the year,
- the heat sinks which are included, which are delimited in spatial terms – for example by means of minimum limit values for heat density [GWh/km²] – as heating network potential areas,
- the spatial level at which balances are compared as an abstraction of transport distances (a certain radius around heat sinks or regional authorities such as cities and municipalities, for example),
- the plausible costs for boreholes, plant engineering and the transport of heat from the borehole location to the end customer; the amount of empirical data available in this connection is sparse, and the data which are available fluctuate widely,

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[1] Among other things, this applies to the research projects that are currently being carried out with the aim of improving the availability of data on usable deep geothermal resources in North Rhine-Westphalia.

- the heavy dependence of operating costs on electricity prices (approximately 1 MWh_{el} of pumping current per 10 MWh_{th} is used for the circulation of water volumes), which in turn depends heavily on the levies and charges to be paid from a business perspective.

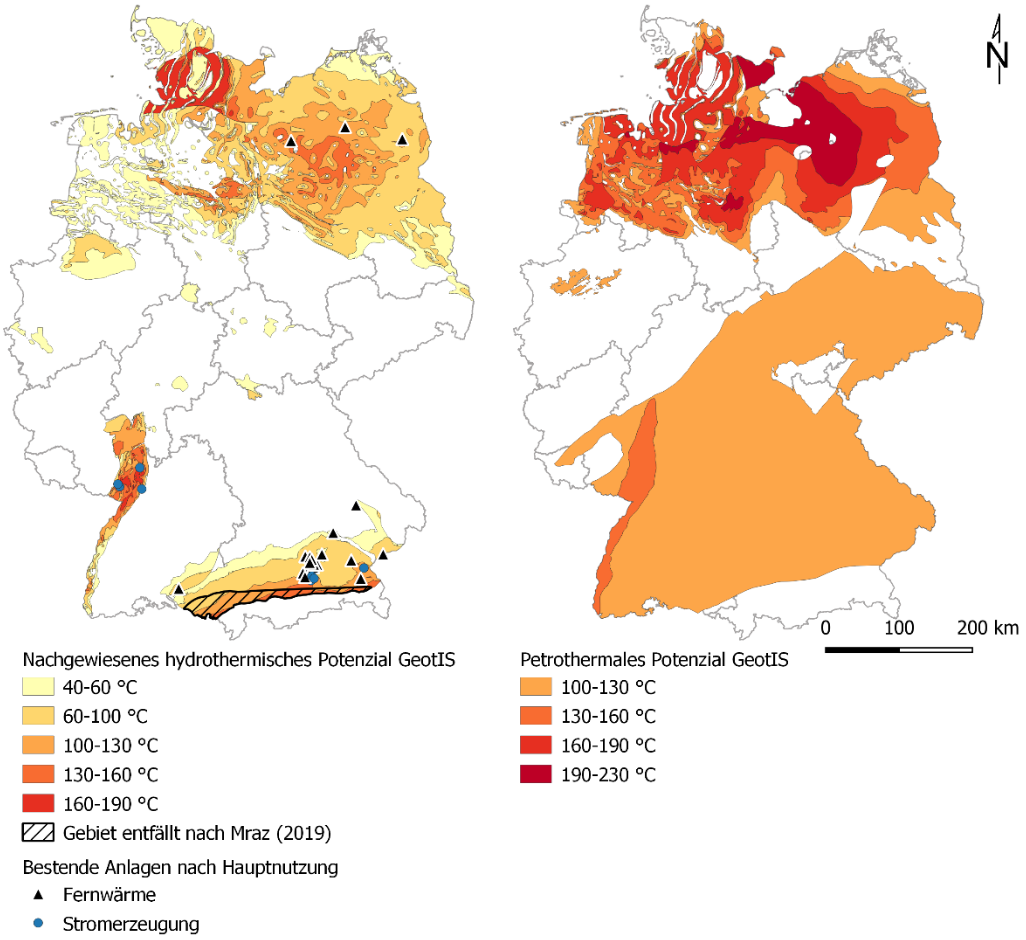

Figure 20: Location of proven hydrothermal reservoirs and petrothermal reservoirs according to temperature in the geothermal information system GeotIS. Own illustration based on Agemar et al. (2014), LIAG (2020).

Nachgewiesenes hydrothermisches Potenzial GeotIS	Proven hydrothermal potential according to GeotIS
Gebiet entfällt nach Marz	Area omitted according to Mraz
Bestende Anlagen nach Hauptnutzung	Existing plants based on primary use
Fernwärme	District heating
Stromerzeugung	Generation of electricity
Petrothermales Potenzial GeotIS	Petrothermal potential according to GeotIS

On the basis of GeotIS and the operating data for current deep geothermal projects in Germany, Sandrock et al. (2020) quantify the technical supply and demand potentials for hydrothermal deep geothermal energy and petrothermal[1] deep geothermal energy. The following are exempted from the potential regions because the implementation of geothermal projects is not possible or is only possible to a limited extent, on the basis of two scenarios; Scenario A: mineral spring and water protection areas (Zone I, II, IIIA), national parks and nature conservation areas, and Scenario B: the above plus areas protected under the Habitats Directive, bird sanctuaries, landscape conservation areas, wetland areas under the Ramsar Convention, biosphere reserves (core and cultivation zone) and national nature monuments)[2]. The supply potential is quantified on the basis of a density model involving one extraction borehole per 7 km² of ground surface and at the level of the three larger-scale potential regions – South German Molasse Basin, Upper Rhine Plain and North German Basin – with regionally differentiated physical parameters for thermal water (density and heat capacity) and achievable extraction rates and standard assumed hours of full utilisation for heat-only power plants of 2 500 h/a and a risk discount applied to the supply potential for unsuccessful boreholes of -25%. In addition, two different reinjection temperatures (T_2) of 65 °C and 35 °C are assessed for each scenario (corresponding approximately to the heat sink return flow temperatures).

Sandrock et al. (2020) quantify the final energy demand potential that can be accessed via heating networks on the basis of the EU28 hectare grid dataset *Heat Demand 2015* from the *Pan-European Thermal Atlas, Version 4.1*. This includes the final energy demand for space heating and hot water in private households and in the commerce, trade and services sector in the base year 2015. The comparison of balances is carried out for heating network potential areas with a heat demand density of >120 TJ/km² (>33.3 GWh/km²) and an allocation of supply potentials in a 2-km search radius around these areas. Distribution losses are ignored. The study does not include a projection of the future usable potential or an assessment of economic efficiency.

A correction of the results based on an evaluation of the updated GeotIS data according to Mraz (2019) results in **technical demand potentials for the base year of 57 TWh at T_2 = 65 °C or 117 TWh at T_2 = 35 °C,** excluding water protection areas, national parks and nature conservation areas.

For the purpose of calculating future **potentials** for **2030 and 2050**, the **technical demand potentials** calculated according to Sandrock et al. (2020) for the base year 2015 are combined with the simulated changes in heat demand from a further potential analysis of deep geothermal energy by Jochum et al. (2017).

Jochum et al. (2017) assess the hydrothermal supply potential on the basis of GeotIS (last updated 2016) with more generic assumptions regarding the physical properties of the reservoirs compared to Sandrock et al. (2020); however, they quantify the future technical and economic usable demand potentials of hydrothermal deep geothermal and estimate the heat production costs on the basis of building stock simulations. **Jochum et al. (2017)** model the **demand potential** on the basis of a spatial database of 17.4 million individual residential buildings categorised by energy type at the level of useful energy for space heating and hot water in the base year 2011, and on the basis of two energy renovation scenarios for the reference years 2030 and 2050. Heat demand in the commerce, trade and services sector

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[1] This study does not contain any further analysis of petrothermal potentials.
[2] This study does not contain any further analysis of the second scenario (B)

or the industrial sector is not included. A comparison of balances for the purpose of quantifying usable demand potential is carried out using a Germany-wide analytical grid (edge length of 1 km), again at the level of useful energy. The transport of heat is not shown.

Jochum et al. (2017) conclude that the technical demand potentials – taking into account the changes in heat demand – will reduce by around 7% by 2030 and by around 25% by 2050 compared to the base year 2011 in the event of moderate renovation; in the event of ambitious renovation, they will reduce by 19% by 2030 and by 45% by 2050. Intersection of these development factors with the technical demand potentials of Sandrock et al. (2020) of 57 TWh (T2 = 65 °C) or 117 TWh (T2 = 35 °C) results in **ranges for technical demand potential of 37-108 TWh for 2030 and 31-88 TWh for 2050**.

The analysis of economic potentials carried out by Jochum et al. (2017) is based on a standard limit value for the specific heat production costs of hydrothermal deep geothermal energy of <EUR 75/MWh$_{th}$. This reduces the technical potentials for the base year by approximately 56%. The technical potentials in 2030 are reduced by 57% (normal renovation of the building stock) or 62% (ambitious renovation). A 70% reduction of technical potential (moderate renovation) and 72% reduction (ambitious renovation) is calculated for 2050. **Economic potentials of 18-46 TWh for 2030 and 9-32 TWh for 2050** can be calculated on this basis.

7.2 Near-surface geothermal energy

7.2.1 Introduction

Near-surface geothermal energy is predominantly accessed by means of brine/water-source heat pumps that use geothermal probes as a source of heat. Other methods of making heat accessible, such as groundwater wells (water/water-source heat pump), geothermal collectors, heat posts or heat baskets, have conquered much smaller shares of the market. Near-surface geothermal energy can be made accessible on a centralised basis (local and district heating networks) or a decentralised basis (in the building stock).

Near-surface geothermal energy can also be deployed in private households, the commerce, trade and services sector and industry. The efficiency of heat pumps depends directly on the rise in temperature, and therefore on the flow temperature of the heating system or the heating network. It follows that they are primarily suitable for efficient buildings and/or buildings with panel heating systems (wall or underfloor heaters) or for heating networks with low flow temperatures. Buildings with a systematically high level of demand for hot water are less suitable for decentralised applications, however.

Development of near-surface geothermal energy using heat pumps is associated with comparatively high capital costs for boreholes and devices (Hinz, 2015). This is balanced out by low operating costs (Günther, 2013). As a basic principle, designs based on a combination with other heat sources lengthen the amortisation period of the investments. Hybrid solutions with other heat sources can nevertheless be useful. For example, a heat pump using an additional heat generator is only an option if the latter commences operation as a backup boiler when the outdoor temperature is particularly cold. Combinations with solar thermal systems can also be beneficial if the solar thermal capacity of the ground is to be regenerated or if the temperature is to be raised (operation in storage mode) so that the annual coefficient of performance of the heat pump can be increased.
A combination of electrical heat pumps with PV systems can be economically advantageous

if large quantities of PV electricity are used on site. Compared to air-source heat pumps (see 6.1and 6.2), ground-source heat pumps regularly achieve higher levels of efficiency, since the source temperature (ground or groundwater) during the heating period is higher and the temperature difference which the heat pump must overcome is accordingly lower. Unlike air-source heat pumps and other heating systems, the energy produced from near-surface geothermal systems can be stored on a seasonal basis.

As a basic principle, heat pumps also have the potential to supply cooling if they are operated 'in reverse'. The heat source of the heat pump (ground, water, air) is used for recooling in the process. The cooling output is lower than in the case of systems designed primarily for cooling, however.

Near-surface geothermal energy can also be used to supply district or local cooling. On the customer side, cooling can be used either directly or as recooling for decentralised cooling systems. From the perspective of the temperature source, ground temperatures can also be regenerated by means of summertime operation.

7.2.2 Total heating and cooling potential and classification

This section opens with a description of the technical and economic potentials for near-surface geothermal energy in Germany, which draws on various studies. Table 16 provides an overview of the ranges of the potentials specified in the literature and the analyses that have been carried out. The individual sources of data are examined below, and the procedure followed in order to obtain the relevant potential results is outlined.

Table 16: Overview of results of potential analysis for near-surface geothermal energy

Energy source (TWh/a)	**Technical potential**		**Economic potential**	
	2030	**2050**	**2030**	**2050**
Total near-surface geothermal energy	**289-652**	**233-594**	**27-170**	**49-294**
Decentralised heat pumps	**207-244**	**124-186**	**6-65**	**13-159**
Centralised heat pumps	**82-408**	**109-408**	**21-105**	**36-135**

Jochum et al. (2017) investigated the potential of decentralised brine/water-source heat pumps in residential buildings. The extraction rate from the ground is compared against the heat demand of the buildings in seven typical housing blocks. The maximum probe number was calculated on the basis of a sample of 210 housing blocks at seven defined urban densities, taking into account minimum distances, structures, infrastructures and tree populations. The maximum probe count for the typical housing blocks was extrapolated to Germany as a whole using a GIS heat map accurate to the nearest building. Further restrictions such as water protection areas and regionally differentiated extraction rates were taken into account. Since the future potentials depend on changes in consumption of useful heat, they were calculated for two maximum scenarios. The **technical supply potential** of brine/water-source heat pumps for residential buildings in Germany ranges from 207 to 244 TWh for 2030 and 124 to 186 TWh for 2050. The highest proportion of coverage is achieved under the 'Committed climate action' scenario in 2050, and corresponds to 66% of useful heat consumption. The potential of the brine/water-source heat pumps is offset by restrictions that apply to all types of heat pumps, particularly in cases where heat is transferred into a room (see also Section 6.1). Heat pumps cannot provide arbitrarily high temperatures. They achieve their highest efficiency at low system temperatures. This must be balanced against the heat output of radiators or panel heating systems, which must cover the heating load of the rooms. This output increases in step with system temperature. The heating load in inefficient buildings is often so high that these buildings cannot be adequately heated at the system temperatures at which heat pumps operate efficiently. Up to a specific heating demand of approximately 120 kWh/m²a, use of a heat pump can be made possible through the replacement of radiators. Heat pumps cannot be used efficiently above this temperature. This limit only applies under ideal conditions, however. In practice, it is assumed that heat pumps cannot be operated in an economically viable manner in buildings with a heating demand of over 90 kWh/m²a. This limit is therefore used as a basis for calculating the potential.

The calculation of **economic potentials** is subject to a great deal of uncertainty. The results are influenced to a particularly significant extent by future changes in device prices (taking into account effects of scale) and changes in energy costs or their components (such as CO_2 prices). The economic potentials are therefore less universally valid than the technical potentials; instead, they apply only with reference to the framework data that are used as a basis in each case. This is also evident from the large range of economic potentials. The economic potential of decentralised brine/water-source heat pumps is calculated on the basis of the scenarios outlined in **Fraunhofer ISE (Sterchele et al. 2020)** and **Gerhardt et al. (2019)**. Consideration is also given to Purr et al. (2019). **Sterchele et al. (2020)** calculated the cost-optimised shares of heat generators for four different scenarios on the basis of the optimisation model REMod: ‘Reference’, ‘Inertia’, ‘Lack of acceptance’ and ‘Sufficiency’. All scenarios achieve a CO_2 reduction of 95% by 2050 compared to 1990. The shares of the individual heat-generating technologies can be regarded as their economic potential under the specific constraints of the relevant scenario. The potential of all heat pump types for 2030 accordingly lies within a spectrum extending from 18.5 to 93 TWh. The spectrum of values for 2050 extends from 109 to 310 TWh. A figure for brine/water-source heat pumps as a share of overall potential for all heat pump types can only be specified on the basis of a further approximation. Sterchele et al. (2020) provide figures for air-source and ground-source heat pumps as a share of the total number of heating systems. The term ‘ground-source heat pumps’ has a wider scope than just the brine/water-source heat pumps with geothermal probes referred to above, since it also covers geothermal collectors, heat baskets and similar technologies. They can all be grouped under the umbrella term of near-surface geothermal energy. It is not apparent whether these different types are taken into account in Sterchele et al. (2020). The share of ground-source heat pumps in 2030 is 1.1% for all scenarios, whereas the corresponding share of air-source heat pumps is between 1.5% and 11.6%. The share of ground-source heat pumps increases to 2.3-5.4% in 2050, while the corresponding share of air-source heat pumps rises to 18.5-48.5%. The total potential for heat pumps is divided between the heat sources ‘air’ and ‘ground’ on the basis of these shares. This is an approximation which presupposes – for the sake of simplicity – that the share of heat generators is proportionate to the quantitative share of heat. According to Sterchele et al. (2020), the economic potential of ground-source heat pumps is therefore 7.8-8.1 TWh in 2030 and 13.0-31.0 TWh in 2050.

Gerhardt et al. (2019) investigated two different scenarios for changes in building efficiency, and carried out calculations both with and without the use of biomass in the buildings sector. This also results in four scenarios, each of which achieves a CO_2 reduction of 95%. The cost-optimised heating market for these scenarios was identified using the SCOPE optimisation model. Brine/water-source heat pumps account for a share of 6-11% of the heat produced in 2050. This corresponds to a quantity of supplied heat of 21.7-58.2 TWh. An economic potential of brine/water-source heat pumps of 45.8-65.4 TWh is calculated for 2030.

This is higher than the potential for 2050, because brine/water-source heat pumps have an advantage in this context over other heat generators, particularly in partially renovated and non-renovated buildings, and the share of these heat generators will drop significantly by 2050.
Purr et al. (2019) did not apply an economic optimisation model to heat generators with a view to minimising costs for final users. The study shows the distribution of ground-source heat pumps for five scenarios, however, taking into account energy and resource efficiency. They contribute 6-56 TWh to the supply of heat in 2030, and 114-159 TWh in 2050.
The extreme values from both of the aforementioned studies are incorporated into the final result when calculating the economic potential.

The availability or future potential of local heating networks is of decisive importance when calculating potentials from near-surface geothermal systems in local and district heating networks. Further restrictions exist in connection with availability of land, lack of access to the subsoil owing to the sealing of surfaces, local requirements concerning permits and the subsoil extraction rates for the given location. In addition, the deployment of centralised heat pumps that use near-surface geothermal energy as a heat source is not possible in water protection areas, in the vicinity of water bodies and in certain other areas on the basis of geological criteria. In most cases, however, very small-scale local restrictions can be circumvented by identifying another location within the relevant heating network area where the heat source can be made accessible and which is not subject to the relevant restrictions. The following procedure is selected for the purpose of obtaining an **approximate estimate of the potential of near-surface geothermal energy in heating networks**: with reference to the existing heating networks and potential district heating expansion areas, the technical potentials are calculated on the basis of typical hours of full utilisation. As with the procedure for centralised air-source heat pumps, the economic potential is calculated on the basis of a reduced district heating network potential (for further details, see also Section 6.2.2). This means that energy prices and the local availability of further renewable energy sources in the area are explicitly excluded from the analysis.

In line with the procedure described in Section 6.2.2, the upper limit of technical potential is calculated on the basis of the quantity of heat that can be discharged into potential heating networks, which in turn is calculated using the open source mapping and planning tool Hotmaps[1]. For this purpose, a minimum heat density of 150 MWh/a per hectare and a minimum heat demand of 10 GWh/a per heating network is calculated as the limit value for 2016 on the basis of a heat density map with high geographical resolution (100 m x 100 m grid cells) for Germany. **This accordingly results in a technical heating network potential of 544 TWh for Germany.**

On the basis of the scenarios outlined by Sterchele et al. (2020), the economic heating potential is calculated using assumed heat sales in heating networks of 110 TWh (2020), 140 TWh (2030) and 180 TWh (2050). These scenarios incorporate economic optimisation of the overall energy system. The potentials relate to the district heating used for space heating and hot water in all sectors.

An assumed coverage rate in heating networks of approximately 25% results in an upper threshold for technical potential of 136 TWh; a coverage rate of up to 75% results in potentials of up to 408 TWh. With reference to the lower economic heat sales in heating networks, the economic potential is approximately 28 or 83 TWh (2020), 35 or 105 TWh (2030) and 45 or 135 TWh (2050). Discount factors are applied below in order to map indirectly any further local restrictions, in particular those concerning water protection areas, availability of land or restricted options for integration into heating networks with high flow temperatures; the

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[1] https://www.hotmaps.hevs.ch/map

technical and economic potentials that are calculated are correspondingly subject to restrictions. In turn, the discount factors are based on those used as a basis for calculating the potentials for centralised air-source heat pumps (discount factor of 50% for 2020, discount factor of 40% for 2030, discount factor of 20% for 2050). The ranges of potentials to which discount factors have been applied accordingly represent 60-100% (2030; discount factor of 40%) or 80-100% (2050; discount factor of 20 %) of the calculated potentials. The potentials calculated in this way are of a similar magnitude to the economic potentials calculated in Gerhardt et al. (2019) (between 70 and 88 TWh in 2050).

The potential for the supply of cooling from centralised near-surface geothermal systems cannot be quantified since no potential studies are available for Germany. Key influencing factors include the availability of a cooling network, local cooling demand and the specific features of the geothermal boreholes. A direct cooling procedure is typically used for near-surface geothermal energy, i.e. circumventing the heat pumps under certain circumstances (only the circulating pumps need to be operated). In the case of systems designed to operate in heating mode, advantage is taken of the fact that the temperature difference between the room air and the source has the opposite sign (plus/minus) in summer. As in the case when the system is combined with an additional heat source, this promotes regeneration of the connected reservoir, and the annual coefficient of performance rises.

7.3 Mine water

7.3.1 Introduction

Mine water is water that is conveyed to the surface using dewatering systems in underground and surface mines. There is often a continuing need to pump mine water out of deep underground mines even after they have been decommissioned to avoid environmental damage caused by a rise in mine water levels ('burdens in perpetuity' in the case of bituminous coal mining). While underground mines are in operation, sump water and groundwater are continuously pumped out of the mine opening to keep the groundwater level low and to facilitate resource extraction. Both mine water and sump water are referred to below using the umbrella term 'warm mine water'.

The thermal potential of warm mine water with a maximum temperature of 35 °C is accessed via heat exchangers and raised to a higher temperature using heat pumps; it can be used for heating or for cooling.

The mine water system at Reiche Zeche mine in Freiberg (Saxony), which supplies heating and cooling to a university building accommodating server and laboratory rooms, is a best practice example (see Figure 21). Water can be extracted at two different points in this system: in the Rothschönberg Adit, warm water at a temperature of approximately 15 °C is used from a depth of 228 m when the demand for cooling dominates. In addition, it is possible to use the deep water extracted from the Reiche Zeche mine shaft at a temperature of approximately 19 °C when the demand for heating dominates. The return flow from the heating circuit is then stored for cooling applications, which results in a particularly high level of efficiency when cooling and heating demand is simultaneously present (Fieback et al. 2019).

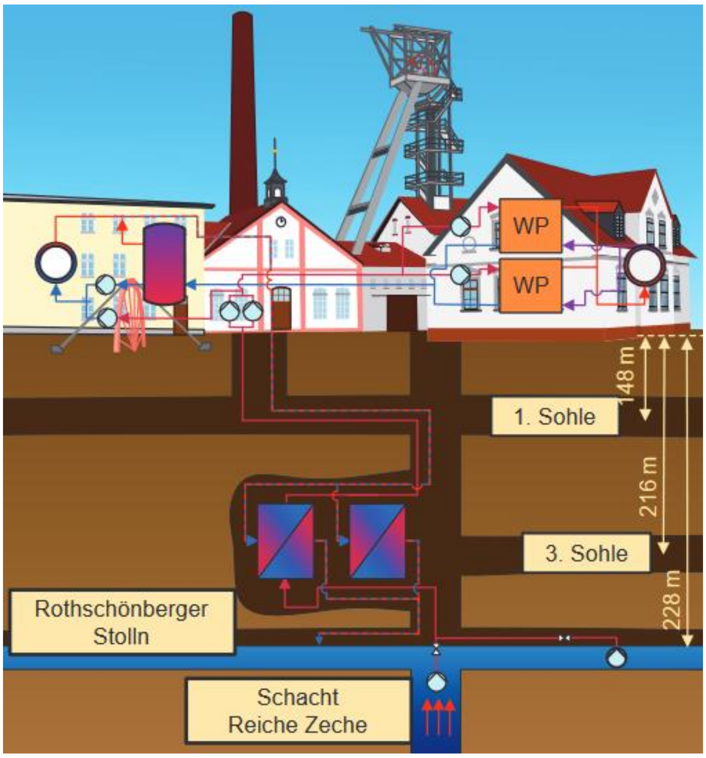

Figure 21: Diagram of the mine water system at the Reiche Zeche mine (Freiberg). Source of image: TU Freiberg.

WP	Heat pump
1. Sohle	First level
3. Sohle	Third level
Rothschönberger Stolln	Rothschönberg Adit
Schacht Reiche Zeche	Reiche Zeche mine shaft

7.3.2 Total heating and cooling potential and classification

This section opens with an overview of the calculated potentials in Table 17. This is followed by a description of the methodology followed to calculate the potentials, which is based on extensive literature research and a synthesis of various sources.

Overall, the total technical potential for warm mine water in Germany calculated on the basis of the above estimates is 7.53 TWh/a (2030) and 2.4 TWh/a (2050). The economic potential is 3.58 TWh/a and 1.78 TWh/a (2030 and 2050), which is somewhat less than half of the technical potential. The drop in potentials between 2030 and 2050 is primarily attributable to the shut-down of German lignite mining by 2050. Most surface lignite mines will be decommissioned by 2040 at the latest, and it is likely that no surface mines at all will be operating in Germany by 2050; this means that it will be impossible to use sump water for energy-related purposes, since once the mines have been flooded it will no longer be necessary to pump water out of them.

Table 17: Overview of results of potential analysis for mine water.

Energy source (TWh/a)	**Technical potential**		**Economic potential**	
	2030	**2050**	**2030**	**2050**
Warm mine water: North Rhine-Westphalia (LANUV potential study Bracke et al. 2018)	**5.89**	**1.54**	**2.64**	**1.12**
of which:				
- Mine water:	**1.20**	**1.44**	**1.05**	**1.10**
- Sump water:	**4.60**	**0**	**1.57**	**0**
- Ore/slate shafts:	**0.09**	**0.10**	**0.02**	**0.02**
Warm mine water: outside North Rhine-Westphalia (own calculations)	**1.64**	**0.86**	**0.94**	**0.66**
of which				
- Mine water:	**0.72**	**0.86**	**0.63**	**0.66**
- Sump water:	**0.92**	**0**	**0.31**	**0**
Warm mine water (Germany)	**7.53**	**2.40**	**3.58**	**1.78**

Different data sources are used to calculate these potentials. The **study on the potential of warm mine water by Bracke et al. (2018) carried out on behalf of the State Agency for**

Nature, Environment and Consumer Protection in North Rhine-Westphalia [Landesamt für Natur, Umwelt und Verbraucherschutz NRW, LANUV] is used as the main reference. This study calculates the regional heating potentials of the warm mine and sump water in mining infrastructures (either abandoned or still in operation) in North Rhine-Westphalia.

It matches up locations where warm mine water is available with existing heat sinks (district heating catchment areas). The economic potential is calculated using a GIS-based algorithm in order to determine the nearest possible and most economically accessible heat sinks in the immediate vicinity of the dewatering system. An iterative and multi-stage filtering process is followed to ensure that the only heat sinks identified as potential customers are those that could be supplied on an economically feasible basis.

The potentials for North Rhine-Westphalia for 2030 (interpolated) and 2050 (directly copied) are scaled up in each case to obtain the potential from warm mine water for Germany as a whole. The following data sources are used for scaling purposes:

- **Study on the potential of mine water in Saxony by Jordan et al. (2001)**: This study identifies the technical and economic potentials for warm mine water from Saxony's metal ore mines and bituminous coal mines using a points-based system.
- **Data from RAG AG (Van de Loo 2016)** on the mine dewatering systems at former bituminous coal mines in North Rhine-Westphalia and Saarland.
- Data on Germany's lignite surface mines outside North Rhine-Westphalia in Saxony (operator: Romonta), Saxony-Anhalt (operator: Mibrag)[1] and Brandenburg (operator: LEAG)[2]: discharge volumes, discharge temperatures and planned decommissioning of the sites[3].

Bituminous coal (mine water)

The mine dewatering systems in the Ruhr, the Rhineland and Ibbenbüren are located in North Rhine-Westphalia and are accordingly taken into account in Bracke et al. (2018). Germany's other mining regions in Saarland and Saxony (e.g. the Döhlen Basin, the Lugau-Oelsnitzer coal field and the Zwickau coal district) and individual mines in Lower Saxony and Saxony-Anhalt are not included by Bracke et al. (2018) and are therefore estimated on the basis of data from Jordan et al. (2001) and Van de Loo (2016). Compared with North Rhine-Westphalia, however, the volumes extracted elsewhere in Germany are very small (bituminous coal extracted in the Ruhr: approximately 10 billion tonnes, quantity extracted elsewhere in Germany: approximately 2 billion tonnes, of which in Saxony approximately 410 million tonnes in total).

The RAG data show that the volume of extracted mine water in the dewatering systems in Saarland is equivalent to approximately 20% of the volume extracted in North Rhine-Westphalia.
On the basis of the data supplied by Jordan et al. (2001) for mining activities in Saxony, it can be estimated that the volume of extracted mine water accounts for approximately 40% of the mine water potential for dewatering systems at bituminous coal mines in North Rhine-Westphalia.

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[1] Profen: https://www.mibrag.de/de-de/geschaeftsfelder/bergbau/tagebau-profen;
United Schleenhain: https://www.mibrag.de/de-de/geschaeftsfelder/bergbau/tagebau-vereinigtes-schleenhain

[2] Jänschwalde: https://www.leag.de/de/blog/artikel/leag-baut-brunnenanlagen-fuer-drei-seen/;
https://lbgr.brandenburg.de/media_fast/4055/Zeitablauf%20Seen.pdf
Welzow South: Regulations on the Lignite Plan (https://bravors.brandenburg.de/de/verordnungen-213956#2.4)

[3] Information emailed by the operators and, on a supplementary basis: Öko-Institut (2017).

The potentials calculated by Bracke et al. (2018) are therefore scaled up by 60% of their respective value in order to take into account the potential of mine water from German bituminous coal and metal ore mines outside North Rhine-Westphalia for 2030 and 2050.

Lignite (sump water)

Bracke et al. (2018) take into account the most significant sump water potentials in Germany. These are located in the Rhineland (Garzweiler II and Hambach surface mines), with a total sump water volume of 435 million m^3/a and temperatures of 13 °C (Garzweiler) and 21.5 °C (Hambach). The Inden surface mine is excluded from the potential calculations, since it is scheduled to stop operating around 2030.

Seven other active lignite surface mines are located in the Lausitz, Central German and Helmstedt mining districts in Brandenburg, Saxony and Saxony-Anhalt. Two are scheduled for decommissioning in the near future – Jänschwalde (anticipated decommissioning date: 2023) and Amsdorf (anticipated decommissioning date: 2035) – which means that their sump water will not be available for use in future.
The sump water generated in the Profen and United Schleenhain surface mines has a temperature of 8-13 °C, which is too low to guarantee an economically feasible heat supply.

The sump water pumped out of the Nochten, Reichswalde and Welzow-South surface mines in the Lausitz mining district has a temperature of approximately 13-14 °C (total annual volume for all three mines: approximately 250 million m^3). These surface mines are likely to remain in operation until a date between 2040 and 2050. The volume of extracted mine water outside North Rhine-Westphalia is therefore equal to around 50% of the extracted volume pumped out of mines in North Rhine-Westphalia. Owing to the fact that the temperature is lower overall, the resulting heating energy potential is approximately 1 000 GWh/a, which corresponds to 20% of the potential for North Rhine-Westphalia. The sump water potential for Germany in 2050 is zero, since it is assumed that all lignite surface mines will have been decommissioned by this date at the latest. Sump water is no longer generated in former lignite mining landscapes (e.g. flooded lakes); in certain cases, however, thermal use of the lakes created in the former mining landscapes is possible through the use of surface water-source heat pumps.

8 Potential analysis of waste heat and cold

8.1 Definition of the scope of the investigation

According to Article 2(9) of Directive (EU) 2018/2001, '"waste heat and cold" means unavoidable heat or cold generated as by-product in industrial or power generation installations, or in the tertiary sector, which would be dissipated unused in air or water without access to a district heating or cooling system, where a cogeneration process has been used or will be used or where cogeneration is not feasible'.

This definition establishes three criteria: the sector in which the heat or cold is generated (industrial, power generation, tertiary sector), whether the generation of heat or cold is unavoidable, and functional and geographical proximity to heating networks and cogeneration plants that feed into them. A lack of data means that it is difficult to carry out assessments in national potential studies of whether the generation of heat or cold is unavoidable, and the vague nature of the aforesaid requirement to determine whether cogeneration processes in heating networks exist/are planned/are not feasible calls into question the advisability of a word-for-word application of the definition to this potential analysis.

In keeping with the Comprehensive Assessment Heating and Cooling (Steinbach et al., 2020), the following framework conditions are established for the subsequent analysis of the potential of waste heat or cooling in this report:

- this report is based on Directive (EU) 2018/2001 (RED II) and focuses on the overall technical and economical potentials that will be usable in future for heating and cooling supply, in the form of final energy demand potential calculated on the basis of theoretical potential.
- The scope of the analysis and description in the study is based on the plant types referred to in Annex IV to Recommendation (EU) 2019/1659 and Annex VIII to Regulation (EU) 2019/826:
  a) heat generation installations,
  b) waste incineration plants,
  c) industrial plants,
  d) tertiary sector.

Annex IV to Commission Recommendation (EU) 2019/1659 ('WASTE HEAT ACCOUNTING') explicitly states that the definition of waste heat does not include heat from cogeneration plants. Theoretical potentials calculated using the methodology selected for the accounting of waste heat potentials from heat power plants are included in Section 8.3 for information. The majority of waste heat potentials from RES installations in Germany involve the generation of electricity from biomass and deep geothermal energy. The potentials for use of heating and cooling from these sources are quantified on a stand-alone basis in Sections 5 and 7, and are not therefore examined in this section. Only the waste heat quantities that can be used outside the plants are quantified. In view of the lack of data, the criterion referred to in Directive (EU) 2018/2001 and in Annex IV to Commission Recommendation (EU) 2019/1659, namely whether the generation of heat or cold is unavoidable (in the sense that checks should first be carried out to determine whether the generation of heat or cold can be avoided or whether the heat or cold can be used within the plant or business) is not explicitly taken into account in higher-level potential studies. Potentials are therefore analysed on the basis of current industrial and power plant sites.

8.2 Waste heat and cold from industry

8.2.1 Introduction

In the national energy statistics, the 'industrial' sector is defined as manufacturing without refineries, but including quarrying and other mining. In the current Statistical Classification of Economic Activities (NACE 2006[1], Rev. 02 at EU level or National Economic Sectors 2008 in Germany), this corresponds to businesses in Section C, Divisions 10 to 18 and Divisions 20 to 33 (manufacturing sectors) and Section B, Division 08 (other mining and quarrying) (Rohde 2019).

The energy statistics produced by the Federal Ministry for Economic Affairs and Energy [Bundesministerium für Wirtschaft und Energie, BMWi] indicate a final energy consumption of almost 500 TWh in the industrial process heat sector and 10 TWh in the industrial process cooling sector for 2018 (BMWi, 2018). This corresponds to a share of around 20% of total final energy consumption (approximately 2 500 TWh in 2018) in Germany. Process heat applications also play a prominent role within the industrial sector, accounting for a share of approximately two thirds of total final energy consumption (approximately 736 TWh in 2018). At the same time, the share of heat fed into heating networks attributable to industrial waste heat was 1.3 TWh (AGFW 2019) or 2.3 TWh (Destatis 2019b), or in other words less than 2%, which points to the existence of high theoretical potentials that have not been exploited to date. BDEW Bundesverband der Energie- und Wasserwirtschaft e.V. (2017) gives a figure of 7% for the share of industrial waste heat.

Indicators for a preliminary evaluation of the relevance of various industrial sectors with regard to theoretically usable waste heat potentials from production processes include final energy consumption for the application area 'process heat', broken down by temperature (shown in Figure 22). A marked concentration of converted energy quantities in the followed five energy-intensive industrial sectors can be observed:

- C24 - Manufacture of basic metals,
- C20 - Manufacture of chemicals and chemical products,
- C23 - Manufacture of other non-metallic mineral products (cement, limestone, plaster),
- C17 - Manufacture of paper and paper products,
- C10 - Manufacture of food products.

Figure 22 illustrates firstly the particular significance of high-temperature processes throughout the industrial sector (around two thirds of process heat applications use temperatures above 500 °C and up to over 1 000 °C), and secondly the heavy concentration of process temperatures >1 000 °C in the economic sectors 'Manufacture of basic metals' (C24) and 'Manufacture of other non-metallic mineral products' (C23). Temperatures between 500 °C and 1 000 °C account for a very high proportion of the processes involved in the manufacture of basic chemicals (C20.1), which is the second-largest economic sector with reference to final energy inputs for process heat. Most of the process temperatures involved in the manufacture of paper and paperboard (C17) are situated within the range 100-500 °C; furthermore, processes at a temperature of below 100 °C account for more than 50% of processes in the food industry (C10).

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[1] Statistical Classification of Economic Activities in the European Community (French: Nomenclature statistique des activités économiques dans la Communauté europèene)

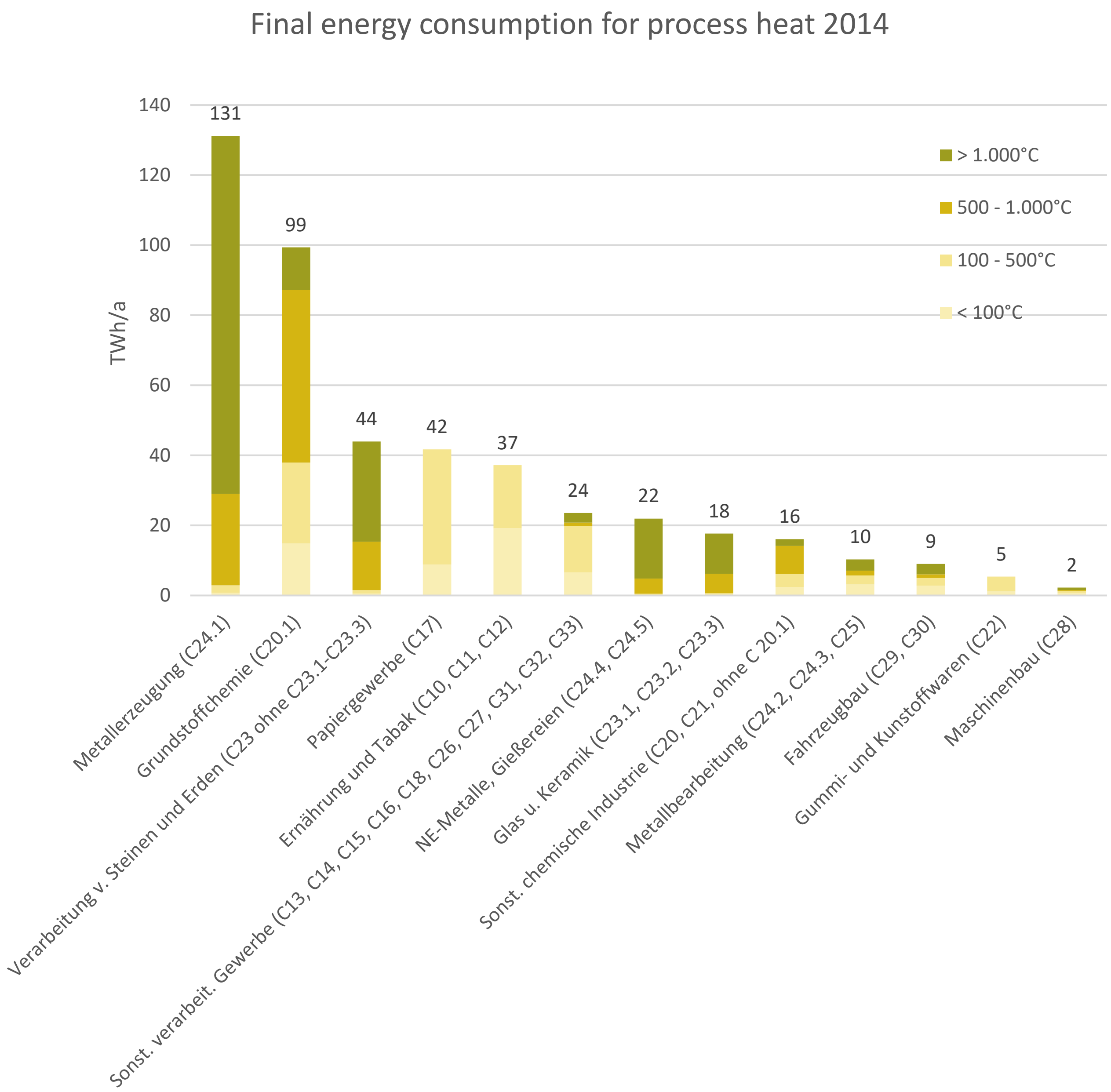

Figure 22: Final energy inputs for process heat production in the manufacturing sectors in 2014, according to temperature. Own illustration on the basis of Rohde (2017) and Eikmeier et al. (2005).

Endenergieverbrauch Prozesswärme 2014	Final energy consumption for process heat 2014
TWh/a	TWh/a
Metallerzeugung (C24.1)	Manufacture of metals (C24.1)
Grundstoffchemie (C20.1)	Manufacture of basic chemicals (C20.1)
Verarbeitung v. Steinen und Erden (C23 ohne C23.1-C23.3)	Manufacture of other non-metallic mineral products (C23 without C23.1-C23.3)
Papiergewerbe (C17)	Manufacture of paper and paperboard (C17)
Ernährung und Tabak (C10, C11, C12)	Food and tobacco (C10, C11, C12)
Sonst. Verarbeit. Gewerbe (C13, C14, C15, C16, C18, C26, C27, C31, C32, C33)	Other manufacturing sectors (C13, C14, C15, C16, C18, C26, C27, C31, C32, C33)

NE-Metalle, Gießereien (C24.4, C24.5)	Non-ferrous metals, foundries (C24.4, C24.5)
Glas u. Keramik (C23.1, C23.2, C23.3)	Glass and ceramics (C23.1, C23.2, C23.3)
Sonst. Chemische Industrie (C20, C21, ohne C20.1)	Other chemical industry (C20, C21, without C20.1)
Metallbearbeitung (C24.2, 23.3, C25)	Manufacture of metals (C24.2, 23.3, C25)
Fahrzeugbau (C29, C30)	Manufacture of motor vehicles (C29, C30)
Gummi- und Kunstoffwaren (C22)	Rubber and plastic products (C22)
Maschinenbau (C28)	Manufacture of machinery (C28)

Building on this rough indication of sector-specific process heat demands and the temperatures required within production processes based on the state of the art, many waste heat potential studies follow a top-down approach by applying technically usable waste heat quotas (derived from various empirical samples) to sector-specific energy consumption data (Pehnt et al. 2010, Groß und Tänzer 2010, Persson et al. 2014, Papapetrou et al. 2018). This approach is also suitable for obtaining a rule-of-thumb estimate for technically usable waste heat potentials. Certain studies use more comprehensive empirical surveys and more detailed data sources at the level of individual industrial sites for the purpose of carrying out a more granular comparison of the relevant parameters for individual waste heat sources and potential heat sinks (temperature, temporal availability and in particular geographical distance in the event of off-site use). At national level, this includes in particular emissions data from installations that are subject to authorisation pursuant to the Eleventh Federal Immissions Control Ordinance [11. Bundesimmissionsschutzverordnung] and site-specific CO_2 emissions from the European Pollutant Release and Transfer Register (E-PRTR) or the ETS. An overview of the available sources of data that can be used as a basis for estimating the technical and economic usable waste heat potential from industrial production processes is provided below.

8.2.2 Total heating and cooling potential and classification

Blömer et al. (2019) carry out a GIS-based bottom-up spatial analysis as a basis for comparing the theoretical waste heat potentials (which are covered by the blanket classification of ‘externally usable’) against the heat sink potentials for space heating demand and hot water demand in the building stock in 2030, using a Germany-wide buildings database[1]. A distance-based spatial source/heat allocation was applied for three energy balance scenarios, depending on the transition temperature required for the relevant heating network circuit (100 °C for the ‘Reference’ scenario, 80 °C for the ‘Forward-looking’ scenario and 50 °C for the ‘Progressive’ scenario). In an additional stage, three variants of plausible reference costs of full heating supplied to end customers of EUR 120/MWh, EUR 100/MWh and EUR 80/MWh were calculated for the purpose of quantifying the economically usable share of technical demand potential at a transition temperature of 100 °C. In the production of the site-specific energy balances, two separate modules for passive or active heat use[2] were used as a basis for the calculations, depending on the waste heat temperature and the sink temperature applied, with the corresponding technical and economic parameters. The theoretically available waste heat potential is accordingly 52-63 TWh, the technically usable

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[1] https://www.ifeu.de/methoden/modelle/waermeatlas/ (accessed on 7 July 2020).

[2] Valorisation of waste heat using a heat pump

waste heat potential is 11-29 TWh and the economically usable waste heat potential is 10-21 TWh.

Industrial waste heat as a source of energy is ascribed a key role by many representatives of the district heating sector and by energy utilities as a medium-term alternative to fossil fuel-based production capacities. The study by Blömer et al. (2019) reveals that around one third of the current supply potential could be used on a grid-bound basis in technical and economic terms by 2030. The potentials that are calculated (20 TWh/a) correspond to approximately 15% of the current net heat production in general supply networks (Destatis 2019b). With reference to the entire consumption of useful heat for space heating and hot water, the long-term share of industrial waste heat is 4-5%, based on a continuation of the current trends in heating demand. Estimates of the supply potential available in the long term are subject to uncertainty, since this potential is heavily influenced by economic developments (choice of site, plant closures) and technological advances (e.g. process modifications, efficiency measures). The analysis is therefore restricted to current economic structures, and was based on current industrial sites. The potentials calculated for 2050 are subject to a particularly high level of uncertainty, since these potentials may be further reduced through changes in commercial locations and the substitution of fossil fuels with renewable energies and electricity-based applications. In turn, consideration of other types of energy such as latent heat (moisture content in exhaust gases) and radiant energy would increase potentials. Media flows such as process waste water, process exhaust air or explicitly 'destroyed' waste heat from cooling processes could also further increase the potential. Many undertakings use central cooling installations for production with coolant temperatures of 35-40 °C. The coolant could be used as a source of heat for high-capacity heat pumps, thereby allowing its utilisation for the supply of heating and cooling. No centralised databases exist that could be used as a basis for robust estimates of these potentials, however. On-site use of waste heat could also further increase the potential, although explicit consideration must be given to the temperatures required for operational purposes and the temperatures of the flue gas stream of the waste heat.

Evaluations of the data that are currently available indicate a heavy geographical concentration of industrial energy sales around large raw material production sites on the one hand, and low-temperature waste heat flows on the other. The geographical availability of industrial waste heat is therefore limited, and the costs involved in making it accessible depend on the temperature requirements of the heat sinks. In practice, the transaction costs between potential suppliers and customers and mandatory legal obligations would furthermore act as structural obstacles to the off-site use of waste heat. In this context, the technical and economic potentials for the grid-bound use of industrial waste heat in 2030 and 2050 shown in Table 18 can be regarded as plausible.

Table 18: Overview of results of potential analysis for industrial waste heat.

Energy source (TWh/a)	Technical potential		Economic potential	
	2030	2050	2030	2050
Industrial waste heat (grid-bound use)	**23-29**	**17-21**	**19-21**	**14-15**

8.3 Waste heat and cold from heating power plants

8.3.1 Introduction

In keeping with the approach outlined in Section 8.1, i.e. on the basis of Annex IV to Commission Recommendation (EU) 2019/1659, the investigation of waste heat potentials from electricity generation plants focuses on heating power plants, since heat from cogeneration plants within the meaning of RED II does not qualify as waste heat. In this context, abstraction of the technical utilisation concept for the purpose of quantifying a technical demand potential for waste heat from heating power plants without targeted coupled heat production (e.g. in the form of passive use of condensate from the cooling circuit in order to cover low-temperature heat demand in greenhouses or similar, or active cooling of exhaust gas flows for the use of latent heat from the condensation of water components) is not possible on the basis of the available studies. Initially, therefore, the theoretical supply potential will be accounted for in keeping with the *Best practices and informal guidance on how to implement the Comprehensive Assessment* published by the European Commission's DG JRC (Jakubcionis et al. 2015). The difference resulting from the use of fuel for heating power plants and net energy production is shown without any further conversion or transport losses.

In future, the energy quantities converted in thermal power plants and therefore also the theoretical waste heat potential will drop sharply as a result of the growth in renewable electricity production from wind and solar. In view of the decision that has been taken to phase out nuclear energy, nuclear power plants are no longer taken into account in the analysis of theoretical waste heat potential. With regard to coal-fired power generation, the Coal Phase-Out Act 2020 also enshrined in policy a development trajectory towards the decommissioning of all lignite and bituminous coal-fired power plants in Germany by 2038, meaning that in the long term (by 2050) no further potentials for the use of heating or cooling can be expected from these electricity generation plants. In turn, the long-term proportion of gas-fired power plants in the production of electricity depends to a large extent on the respective scenario. No attempt is accordingly made in this study to quantify long-term potentials, *inter alia* in view of the lack of clarity regarding the technical utilisation concept (referred to in the introduction) and the definition of waste heat from electricity generation.

8.3.2 Total heating and cooling potential and classification

The investigation will focus on waste heat from installations that are primarily intended to generate electricity. Utilisation potential cannot be calculated at individual plant level in this respect; instead, only a higher-level theoretical waste heat potential with reference to fuel inputs can be calculated. It follows that a primary purpose of electricity generation cannot be assigned to plants, and this section therefore also accounts for the theoretical waste heat potentials from combined production.

As a basic principle, account should be taken of the fact that the figures relate only to energy quantities discharged into the general supply network. Feed-ins (such as feed-ins from industrial power plants into local networks) are not included and are not considered separately here.

To avoid double counting, the theoretical waste heat potential from biogenic fuels (key number 51–56) and waste (key number 61 und 62) used in electricity generation plants or cogeneration plants are not taken into account in this analysis. The corresponding quantities are accounted for as primary energy or economic biomass potential for the heating and cooling sector in Section 5, or fossil fuel-derived waste heat from waste incineration in Section 8.4. Industrial waste (key number 61) is also not included, in order to adapt the total balance of fuel inputs recorded to the primary source for waste heat from waste incineration used in Section 8.4.

Table 19: Results of the assessment of theoretical waste heat potentials from heating power plants in 2018, based on the Comprehensive Assessment (source: Steinbach et al., 2020).

Energy source group	**Theoretical waste heat potential of uncoupled electricity production [TWh]**	**Theoretical waste heat potential of coupled electricity and heat production [TWh]**
	2018	2018
Bituminous coal	**92.9**	**10.6**
Lignite	**220**	**5.2**
Petroleum products	**4.2**	**2.1**
Gases	**40**	**27**
Other energy sources	**1.2**	**0.4**
Total	**358.3**	**45.3**

The theoretical potentials of waste heat from uncoupled electricity generation in fossil fuel-fired heat power plants (excluding the energy sources uranium, waste and biomass) can be quantified as 358 TWh for 2018. In addition, 45 TWh can be quantified as losses from fossil fuel-fired cogeneration plants in the form of waste heat. Technical and economic final energy demand potentials cannot be quantified on the basis of the current data and studies.

8.4 Waste heat and cold from waste incineration

8.4.1 Introduction

The energy-related use of waste for the production of district heating or process steam is already widespread. In 2018, waste incineration accounted for almost 16% of net heat production in general supply networks, including 11.5 TWh from the incineration of fossil waste and 10 TWh from the incineration of biogenic waste (Destatis 2019b). Additional quantities of heat are used in the form of process steam in local networks or supplied to neighbouring thermal power plants for electricity generation.

Waste incineration plants have a hybrid status from two different viewpoints. Firstly, the primary purpose of the majority of these plants from a permit-related perspective is to dispose of hazardous or municipal waste; their secondary purpose is to act as energy production plants by producing and using large quantities of electricity and/or heat at the same time, and/or supplying the latter to third parties. For the purpose of assessing the waste heat potentials from waste heat incineration within the meaning of RED II, the discussion below will initially be limited to plants whose primary purpose is to dispose of hazardous or municipal waste, in keeping with the debate surrounding the waste hierarchy and the circular economy guidelines at EU level.

In the secondary literature, plants which serve the primary purpose of disposing of municipal waste are assigned either to the category of waste incineration plants or to the category of substitute fuel plants. A distinction is made between older waste incineration plants (installed before 2005) with higher proportions of untreated municipal waste as fuel inputs and lower energy use/conversion efficiency on average, and newer substitute fuel plants with higher proportions of pre-treated waste (‘substitute fuels’) and optimised energy production. In practice, both the firing technologies used and the waste fractions approved for both plant types are identical for the most part, meaning that it is not always possible to delineate them clearly from a technical perspective. Plants whose primary purpose is to dispose of hazardous waste are referred to as hazardous waste incineration plants. These plants are located primarily at integrated chemical industry sites or at waste disposal centres; the recovered energy is typically used in the form of steam within the network of local operations (Flamme et al. 2018).

Table 20 provides an overview of existing plants, the quantities of incinerated waste that can be allocated to these plants and their energy products in 2015 (based on a survey of operators by Flamme et al. (2018)).

Table 20: Overview of existing waste incineration plants in Germany 2015. Orange: plant types investigated for the purpose of assessing potential. Own illustration based on Flamme et al. (2018).

		Input			**Output (gross)**			**Output (net)**		
Type	**Number**	**Capacity [t/a]**	**Mass [t/a]**	**Energy [TWh]**	**Total energy [TWh]**	**Heat [TWh]**	**Electricity [TWh]**	**Total energy [TWh]**	**Heat [TWh]**	**Electricity [TWh]**
Waste incineration	66	20 634 782	20 005 469	57.0	30.4	22.2	8.3	25.4	19.1	6.3
Substitute fuel plants	32	6 310 750	5 714 042	19.4	12.3	8.9	3.4	11.7	8.8	2.9
Hazardous waste incineration	31	1 634 080	1 333 816	6.1	3.9	3.8	0.1	3.4	3.4	
Biomass power plants	*56*	*6 579 671*	*6 579 671*	*23.8*	*9.8*	*3.6*	*6.3*			
Sludge incineration	*27*		*957 932*	*10.3*	*0.0*	*0.0*	*0.0*			
Cement plants	*34*		*3 222 000*	*16.5*	*11.6*	*11.6*	*0.0*			
Coal-fired power plants	*22*	*4 800 000*	*1 509 407*	*3.2*	*1.7*	*0.6*	*1.1*			
Industrial power plants	*31*		*6 100 000*	*23.1*	*17.3*	*11.5*	*5.8*			
Biowaste fermentation	*112*	*4 250 000*	*3 643 093*	*0.0*	*1.6*	*0.8*	*0.8*			
Mechanical-biological waste treatment	*44*	*5 421 100*	*4 375 620*	*0.0*	*0.0*	*0.0*	*0.0*			
Sum of investigated types			**27 053 327**	**82.4**	**46.7**	**34.9**	**11.8**	**40.5**	**31.3**	**9.2**

The majority of waste incineration plants and substitute fuel plants are assigned a hybrid status with reference to the high proportions of biogenic waste fractions in their fuel mix (50% on average), and also with reference to their role as RES production plants; a certain proportion of the electricity and heat that is produced qualifies as renewable. Care must be taken to avoid the double counting of quantities of heat from biogenic waste fractions when quantifying the future waste heat utilisation potential of waste heat incineration. In keeping with the biomass potential survey also carried out within the framework of this report, the waste heat potential from waste incineration will be reduced by the biogenic share of the waste in the following literature review and assessment. Only fossil fuel-derived waste heat quantities from waste incineration are therefore quantified in this section. Given the nature of the studies available on future biomass potentials, which focus on the primary energy potential of residues and waste, this procedure is to be regarded as clearer and more thematically consistent (clear separation of RES and waste heat, frequent lack of information on quantities and levels of utilisation of individual waste and residue fractions in the biomass potential studies which stands in the way of back-casting).

Finally, it should be noted that the waste incineration plants and substitute fuel plants currently in existence, whose primary aim from a permit-related perspective is to dispose of municipal waste, are mainly combined with energy production and operated as CHP plants, and often even achieve the status of high-efficiency CHP plants. Owing to the aforesaid focus on the primary purpose of plants as a criterion for classifying them as waste incineration plants for the purpose of this report, future quantities of useful heat are nevertheless categorised as waste heat, since the cogeneration process or the generation of electricity are regarded only as secondary functions.

Background note: Incineration of sewage sludge

Solid residues from waste water treatment are often still incinerated together with other waste in waste incineration plants, cement plants or coal-fired power plants. With a view to implementing EU requirements concerning the recovery of phosphorus from sewage sludge, separate incineration plants for the incineration of sewage sludge will be constructed throughout Germany by 2030. As a result of the high moisture content of the fuels and the energy required for drying, Flamme et al. (2018) calculate a figure of zero for net useful energy quantities from the incineration of sewage sludge. High biogenic proportions are also present in sewage sludge as a fuel type; these quantities (by way of analogy to the biogenic proportions of incinerated municipal waste for the plant types ‘waste incineration plant’ and ‘substitute fuel plant’) are accounted for in the primary energy biomass potentials.

Nevertheless, the waste heat status of useful heat quantities (where applicable from separate (fossil fuel-fired) production processes for the drying of substrates) should be clarified in standards, and if necessary quantified more precisely on the basis of typical plant designs. Rough estimates carried out by the authors on the basis of planning documents for mono sludge incineration plants indicate a total heat potential of approximately 1.75 TWh/a (fossil and biogenic).

8.4.2 Total heating and cooling potential and classification

The primary data source for the quantification of the usable waste heat potential from waste incineration in 2030 is the study by Flamme et al. (2018). On the basis of a comprehensive survey of plant operators, detailed information about the plants in existence in 2015 was captured, including aggregated data on quantities of incinerated waste, calorific values and the production of heat and electricity (gross and net), all compiled on a differentiated basis for 10 plant types. In conjunction with an analysis of changes in waste volumes, the data are used to project the quantities of treated waste and useful energy quantities for the individual plant types in the reference year (2030). Only gross energy potentials (including own use, without taking into account quantities that are actually exportable) are shown for 2030 (Table 21).

Table 21: Overview of waste treatment in Germany in 2030. Orange: plant types investigated for the purpose of assessing potential. Own illustration based on Flamme et al. (2018).

	Input		Output (gross)			Output (net)*		
Type	**Mass [t/a]**	**Energy [TWh]**	**Total energy [TWh]**	**Heat [TWh]**	**Electricity [TWh]**	**Total energy [TWh]**	**Heat [TWh]**	**Electricity [TWh]**
Waste incineration	19 051 382	52.3	27.9	20.4	7.6	23.3	17.5	5.8
Substitute fuel plants	5 413 788	17.7	11.3	8.1	3.2	10.7	8.0	2.6
Hazardous waste incineration	1 333 816	5.9	3.8	3.7	0.1	3.3	3.3	0.0
Biomass power plants	5 921 704	20.7	8.5	3.1	5.4			
Sludge incineration	2 466 000	25.6	0.0	0.0	0.0			
Cement plants	3 971 000	19.6	13.7	13.7	0.0			
Coal-fired power plants	0	0.0	0.0	0.0	0.0			
Industrial power plants	6 100 000	22.2	16.7	11.1	5.6			
Biowaste fermentation	5 500 000	0.0	2.4	1.2	1.2			
Mechanical-biological waste treatment	4 061 136	0.0	0.0	0.0	0.0			
Sum of investigated types	25 798 986	75.9	43.0	32.2	10.9	37.3	28.9	8.4

*Own calculation on the basis of levels of utilisation for 2015.

The potentials are initially technical potentials. Technical advancements up to 2030 are not taken into account with regard to the levels of energy efficiency of the recycling facilities. It is assumed that the plants currently in existence have already been optimised to the greatest possible extent, although in individual cases there will of course be further potential for improvement in terms of heat utilisation, for example by means of low-temperature district heating networks, greenhouses, mobile heat storage units or the drying of sewage sludge. Efficiency levels are frequently restricted by location, and also depend to a large extent on the feasibility of connecting suitable heat customers. It is deemed unlikely that locations will change to any relevant extent over the next 10-15 years, since the good technical condition of most plants renders this unnecessary, and overcapacities are in any case likely to be present in the future.

In the production of an energy balance for useful heat quantities from the plant types under investigation (waste incineration plants, substitute fuel plants and hazardous waste incineration plants) on the basis of Flamme et al. (2018), consideration should be given to the following points, which in each case give rise to certain assumptions:

- **Range of externally usable waste heat quantities:** the quantity of externally usable heat is influenced by the efficiency of energy recovery/steam generation (including the quantities of energy used in-house), by the share of electricity production and (in particular) by the site-specific quantities of externally usable heat. The aforesaid influencing factors are combined in the thermal net utilisation level, which specifies the externally usable heat quantities in relation to the fuel input (calorific value). Data from previous years indicate that the optimisation potentials within plants have largely been exhausted; other trends that can be observed include an increase in heat exports, *inter alia* through new connections of existing thermal waste treatment plants to heating networks, and a slight drop in the electricity produced by these plants (Flamme et al. 2018, ITAD 2020). Although the potential of new connections has been exhausted for the most part through this process, (Fritz & Pehnt, 2019) identify another two plants.

In this context, the values specified by Flamme et al. (2018) for the net heat utilisation potential in 2030 are used as the lower potential limit. A supplement of +5% on the calculated net utilisation levels of waste incineration plants and substitute fuel plants is assumed as the upper potential limit, as an abstraction of the increases in heat exports to general-supply district heating networks observed since 2015 and projected through to 2030. In the case of hazardous waste incineration plants, the exclusive use of process steam in industrial applications or power plants is assumed. The values specified by Flamme are therefore used directly in this study.

- **Biogenic share of waste:** in the interests of clarity and consistency, biogenic residue and waste potentials are assessed in Section 5. The primary energy biomass potential is specified on the basis of the available data. When quantifying the total potentials from RES and waste heat for the heating sector, care must be taken to avoid the double counting of heat from biogenic residues and waste as an input for the plants investigated within the framework of this study. The study by Flamme et al. does not break down energy sales into biogenic and fossil fuel-derived waste fractions. The following estimate of potentials is therefore based on the biogenic proportion of heat (with reference to net heat production) from waste incineration according to Destatis (2019a) and Destatis (2019b) in the reporting year 2018, namely 46.5% of energy potentials shown in Flamme et al. (2018) for the plant types 'Waste incineration plant' and 'substitute fuel plant'. No biogenic proportions are applied to hazardous waste incineration plants.
- **Conversion to final energy potential:** the figures in Flamme et al. (2018) correspond to the net discharge of heat at the plant boundary. When calculating the final energy potential for the plant types 'Waste incineration plant' and 'substitute fuel plant', which primarily feed into large district heating networks, net losses of 10% are assumed for 2030; the quantities of heat are reduced by this percentage. The quantities of heat from hazardous waste incineration plants are not reduced. No data are available on final energy applications and the corresponding levels of utilisation. The transport of heat over shorter distances (local heating networks) and small numbers of branched pipes is associated with very low losses in practice; loss-free use is therefore assumed for process heating networks.
- **Economic potential:** owing to the widespread refinancing of plants by means of waste disposal systems, the heat production costs of waste incineration plants have been very low and extremely competitive to date. The same principle is applied to the potentials that will be accessible in the future on an economically viable basis, in that the economic potential is assumed to be identical to the technical potential.
- **Potential in 2050:** in view of the high level of uncertainty regarding the long-term role of thermal waste treatment, the potential of waste heat from waste incineration for 2050 is not estimated.

The estimate for 2030 results in a technical and economic final energy demand potential of waste heat from waste incineration plants of 26.3-29.5 TWh. Of this figure, 23-26.1 TWh is accounted for by plants used primarily for the incineration of municipal waste (waste incineration plants and substitute fuel plants), and another 3.3 TWh by hazardous waste incineration plants (the majority of which are integrated into process heating networks). On the basis of the breakdown of net heat production from waste into 46.5% biogenic and 53.5% fossil fuel-derived (Destatis 2019a, 2019b), a fossil fuel-derived final energy demand potential of 15.6–17.3 TWh can be estimated.

With the uncertainties surrounding changes in quantities of fossil fuel-derived waste and (where applicable) discrepancies in the quantities of heat recorded by Flamme et al. (2018) (plant types) and Destatis (2019a, 2019b) (feed-ins into general supply networks) taken into account, **extensive use is already made of the potentials for fossil fuel derived-waste heat**

from waste incineration plants for downstream heat applications at a higher temperature (district heating, process steam). This assessment is based on an internal reconciliation of figures from the industry association ITAD e.V. for heat exports from approximately 80 plants belonging to the association's members between 2016 and 2019.

The potential for 'traditional district heating' that is also accessible by 2030 can be estimated at 1-2 TWh on the basis of a rough comparison of figures. Additional potentials are anticipated in the low-temperature heating sector.

Table 22: Overview of the results of the potential analysis for heating from waste incineration.

Energy source (TWh/a)	Technical potential		Economic potential	
	2030	**2050**	**2030**	**2050**
Waste heat from plants for the disposal of hazardous or municipal waste	**26.3-29.5**	**-**	**26.3-29.5**	**-**
Of which fossil fuel-derived	**15.6-17.3**	**-**	**15.6-17.3**	**-**

A projection for 2050 is not feasible owing to the high level of uncertainty affecting the entire waste management system.

8.5 Waste heat and cold from the tertiary sector

8.5.1 Introduction

The tertiary sector covers all service activities in Sections F to S of the classification of economic activities. The main locations for energy sales involving potential waste heat or cooling potentials can be found in the information and communications sector (data centres) and in restaurants, commerce and warehouses (baking ovens, cooling). One of the challenges involved in accessing the theoretical waste heat potentials in the tertiary sector is the patchwork structure of existing energy flows in comparison to the other sectors under investigation (industry, waste incineration and electricity generation) and the fact that the temperatures are often lower, which requires customers to adapt their usage patterns. Conversely, advantages include geographical availability and proximity to potential heat sinks.

8.5.2 Total heating and cooling potential and classification

Comprehensive studies of waste heat and cold potentials in the tertiary sector have not been carried out in Germany to date.

Rough estimates of waste heat from data centres are available. Data centres typically use air for the purpose of cooling IT equipment. The heat is generally transferred to and removed by a water-based system based on recirculating air handling units fitted with cold water coils. This typically results in cold water return flow temperatures of 18-30 °C.

Through liquid cooling of the IT components, higher temperatures (of approximately 50 °C) can be achieved in the flows of waste heat and higher energy densities can be achieved in the heat transfer medium, allowing more economically feasible utilisation concepts to be implemented. Owing to the higher costs incurred by data centre operators and claims that there is a higher risk of damage in the event of a leak, very few liquid cooling systems have been installed to date.

Potential options for use of the waste heat from data centres include heating the building in which the data centre is located, heating neighbouring buildings, feeding the heat into heating networks or covering (at least in part) specific process heat requirements such as those of swimming pools or greenhouses. In many cases it is necessary to use heat pumps to increase the temperature yet further. The optimisation potentials are identified in pilot projects on the basis of integrated heating and cooling supply concepts.

To date, however, it has only been possible to quantify the supply potential; according to Funke et al. (2019), this can be estimated as 13 TWh of electricity converted into heat.

Quantification is not currently possible.

9 Background note on power-to-heat

Power-to-heat (PtH) systems convert electrical energy into thermal energy. The electrical energy is converted directly using only electrical heat generators. PtH systems are used in households, commerce and industry. They are also used for centralised heat production in district heating networks. PtH is frequently used as an umbrella term for various electricity-based heat production technologies (including heat pumps). This background note will however be limited to electric heating boilers (e-heaters) and electrode boilers (e-boilers) that convert electricity directly into heat at a ratio of approximately 1:1.

In the majority of cases, the method applied to produce cooling in Germany is the conversion of electrical energy into thermal energy by means of compression chillers (see the background note on cooling in Section 4.2.2). Further details on this topic can be found in the background note above on the production of cooling.

Coupling of the electricity and heating sectors makes it possible to use electricity generated on a fluctuating basis from renewable energy sources (wind, photovoltaics). For example, the generation of heat from electricity can be used to avoid situations in which wind turbines have to be curtailed as a result of network congestion. This makes it easier to integrate renewable energy sources into the supply system. At the same time, the use of PtH systems increases demand for electricity (Gerhardt et al. 2014). PtH systems may therefore also be beneficial from the perspective of the energy transition, particularly with regard to the electricity system.

9.1 Relevance of PtH in Germany

Around 36 large-scale PtH systems are installed in district heating supply systems in Germany; the installed outputs range from 0.55 MW up to 100 MW (a PtH system based in Heilbronn) (Christidis et al. 2017), but the average output is around 18 MW. The total installed output is around 555 MW (BDEW 2020). The PtH systems produce heat which is distributed via heating networks or produced directly at the central bulk consumer, and which is used in households, commerce and industry in the form of space heating and domestic hot water.

In the case of decentralised heat production involving the use of electricity, night storage heaters tend to be used in existing buildings, while heat pumps tend to be used in new builds. Electricity also accounts for around 17% of decentralised hot water production in private households.

The discussion below focuses mainly on the use of PtH systems for centralised heat production.

9.2 Best practice example

The electrode boiler ‘Karoline’ is located in Hamburg and has an output of 45 MW. It was put into operation in 2018, and feeds into Hamburg’s district heating network. A notable feature of this PtH system is its location; the boiler was installed in an existing substation, meaning that the peripherals and infrastructure required to supply the PtH system with high-voltage electricity were already in place. Figure 23 shows the expansion of the transformer and installation of the boiler, which was manufactured on the basis of a special custom-fit design to reflect the features of the existing site. The ‘Karoline’ PtH system forms part of one of the major projects implemented under the auspices of the ‘North German Energy Transition 4.0’. Research is to be carried out into the system’s operations to identify the basic technical and economic conditions required for the economically feasible operation of PtH systems that benefit the energy transition. Particularly in North Germany, a great deal of electricity is produced by wind turbines; this electricity sometimes needs to be curtailed as a result of network congestion, but is suitable for use in PtH systems for the flexible production of renewable heat.

Figure 23: ‘Karoline’ electric boiler – a 45-MW PtH system in Hamburg’s ‘Karolinenviertel’ district is installed in a substation (bottom). As part of the ‘North German Energy Transition 4.0’ project, the system plays a role in North Germany’s energy transition. (Source: Vattenfall 2018)

9.3 Mode of operation

PtH systems in the form of electrode boilers or electric heating boilers achieve efficiency levels of up to 99%. Technologies of this kind have already been in use for around 100 years, and have been thoroughly tested. They typically exhibit a very high level of reliability, with virtually round-the-clock availability (Bücken et al. 2017).

PtH systems generally feature infinitely adjustable controls. Their very high load change rates mean that they are suitable (among other things) for use as a source of negative balancing power, and in particular secondary balancing power (Bücken et al. 2017). PtH systems can be operated whenever excess renewable electricity is produced; this allows fluctuating renewable electricity generators to be integrated into the supply system. In this context, it often makes sense to combine PtH production systems with heat storage units or heating networks so that the heat produced at certain times (according to the needs of the electricity market) can be stored.

A distinction is made between different PtH systems on the basis of the technology used, namely electrode boilers or electric heating boilers.

Electrode boilers heat water by passing electricity through it. The water itself acts as ohmic resistance, and is heated directly in the primary circuit. The thermal energy is transferred to a (district heating) system in a heat exchanger. Physical separation of the circuits is necessary owing to the different water conditioning requirements. Electrode boilers are typically connected to a medium-voltage or high-voltage source and are generally used in a higher output range (Christidis et al. 2017).

By way of contrast, electric heating boilers (also known as resistance heaters or (in this report) e-heaters) heat the water indirectly using a heating element that is heated up electrically by resistance heating. In these PtH systems, the (district heating) water that is used can flow directly through the boiler. The electrical conductors inside the heating element need to be isolated, and are typically connected to a low-voltage source. Typical outputs for e-heaters are up to 10 MW, and several modules can be installed in parallel for higher outputs (Christidis et al. 2017).

9.4 Marketing and economic feasibility

The investment costs for PtH systems vary greatly depending on output and the peripherals or infrastructure required at the location. In a study carried out by Agora Energiewende, the investment costs for electric heating boilers are specified as EUR 75-150/kW; this figure does not include the electrical connection costs (EUR 25-150/kW) (Gerhardt et al. 2014). In a further comprehensive study, the investment costs for electric heating boilers are specified as EUR 65/kW (5 MW_{th} plant) and the investment costs for electrode boilers as EUR 88/kW (10 MW_{th} plant) or EUR 50/kW (40 MW_{th} plant) (Bücken et al. 2017). The specific investment costs are lower for larger systems.

PtH systems are more expensive to operate than systems using conventional energy sources if the electricity is obtained externally from the general supply network. Even when wholesale electricity prices are low or negative as a result of excess supply or network congestion, high costs are incurred in connection with obtaining electricity as a result of the levies and taxes to be paid (Renewable Energies Act levy, network usage charge, electricity tax), which heavily distort the market electricity price. As a result, PtH systems frequently obtain electricity from on-site production systems (e.g. highly efficient cogeneration plants or PV installations) with a view to guaranteeing economically feasible operation.

In centralised systems such as heating networks and in industry and commerce, PtH systems are frequently used in combination with cogeneration production plants for the aforesaid reasons. In the event of low electricity prices on the electricity exchange, for example as a result of oversupply through the feed-in of RES electricity, or if there is a demand for negative balancing power, the cogeneration plant might be shut down. Many cogeneration plants cannot be switched off for short periods of time; instead, they are down-regulated to a partial load to ensure that they can be started up again rapidly when they need to be placed into operation. If a PtH system is installed downstream, it uses the remaining electricity produced by the cogeneration plant and provides a greater level of flexibility to the electricity markets, which is remunerated accordingly on the balancing power market. At the same time, the PtH system compensates for the reduced production of heat by the cogeneration plant operating at partial load. PtH systems can also be used to compensate for extreme heat demand peaks, which only occur during a few hours per year (approximately 20-500 h/a).

As a result of the regulatory parameters in place and the associated charges, levies and taxes imposed on the electricity price, an adequate business model has not yet been developed for PtH systems in the field of heating networks. The systems are operated in such a way as to deliver very few hours of full utilisation per year, and have accounted for only a negligible share of district heating production to date.

9.5 Influencing factors and evolution of PtH

The implementation of future PtH projects depends to a large extent on future political, regulatory and economic framework conditions. Relevant factors include revenues from the supply of negative balancing energy, which influence the economic viability of many systems. The current route to market for PtH systems as suppliers of negative balancing power (secondary balancing power or minute reserve) is restricted, however. Market volumes are limited and unit prices and demand charges fluctuate widely; what is more, grid relief is only possible if units are demanded by the grid operators. Additional incentives created by the electricity market and an adapted regulatory framework could further solidify the roll-out of PtH systems.

The option of financing PtH systems through the purchase of excess RES electricity is a further deciding factor in their future. The related legal provision that applies in Germany (incorporated as Section 13(6a) of the Energy Industry Act as part of the amendments to the Renewable Energies Act) has had little impact so far. Obstacles to implementation include the restriction on network expansion areas and the fact that PtH systems cannot be operated in areas where the highest curtailments are to be expected according to the current state of knowledge. In addition, from the perspective of the heat suppliers, the economic and organisational risks are not compensated for by corresponding additional yields under the current regulatory framework. A study by Graz University of Technology which describes these obstacles proposes a strategy of utilising excess RES electricity in PtH systems on a market-oriented basis as a solution (Hinterberger et al. 2018). Other position papers and opinions, such as those produced by an international district heating and cooling and combined heat and power (CHP) association (AGFW), suggest the same conclusions (Kühne 2015).

A further significant economic influencing factor for PtH projects is the building cost subsidy for the network connection of PtH systems. This decisive cost factor is a one-off fee to be paid by the customer during the process of establishing and expanding the connection for the long-term supply of installed power by the network operator. Different studies model the energy system in Germany in 2030 and 2050. Production in PtH systems is also modelled as a technology option for supplying building heat and process heat. A study by the Federation of German Industries [Bundesverband der Deutschen Industrie, BDI] investigates the 80% and 95% GHG reduction scenarios (BDI N80/BDI G95: Gerbert et al. 2018). The study by the Fraunhofer ISE involves calculations based on four different 95% target scenarios, each of which is based on different framework societal situations (ISE scenarios 'Reference', 'Inertia' 'Lack of acceptance' and 'Sufficiency' according to Sterchele et al. 2020). This study does not however contain a breakdown of the production of district heating, meaning that Figure 24 only includes non-grid-bound PtH heating. The RESCUE study by the German Environment Agency (Purr et al. 2019) outlines potential pathways for achieving targets in six target scenarios (95% GHG reduction).

Figure 24 shows the values for PtH-produced final energy for building heat and process heat in TWh/a for 2030 and 2050. PtH-produced heat is also shown as a share of the total heat produced in 2050. Figure 24 illustrates clearly that PtH heat will be highly relevant in future, and will follow an upwards trajectory between 2030 and 2050.

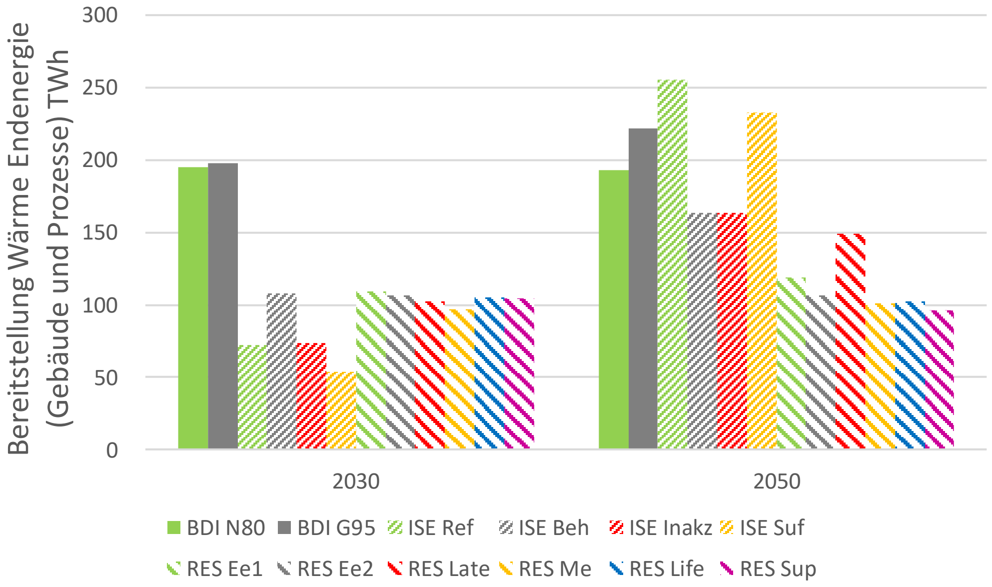

Figure 24: Production of heat in the 'building heat' and 'process heat' applications in 2030 and 2050 calculated by Gerbert et al. 2018 (BDI), Sterchele et al. 2020 (ISE) and Purr et al. 2019 (RESCUE). For 2050: PtH-produced heat as a proportion of the total heat produced.

Bereitstellung Wärme Endenergie (Gebäude und Prozesse) TWh	Supply of heat as final energy (buildings and processes) in TWh
BDI N80	BDI N80
BDI G95	BDI G95
ISE Ref	ISE Reference
ISE Beh	ISE Inertia
ISE Inakz	ISE Lack of acceptance
ISE Suf	ISE Sufficiency
RES Ee1	RES Ee1
RES Ee2	RES Ee2
RES Late	RES Late
RES Me	RES Me
RES Life	RES Life
RES Sup	RES Sup

9.6 Conclusion

Analysis of the current marketing options and the existing obstacles to the integration of PtH systems reveals that the potential depends firstly on the installed PtH system output, and secondly (and to a large extent) on the long-term availability of renewable electricity. Furthermore, the economic potential of PtH systems deployed in Germany also depends to a large extent on the future regulatory framework conditions that apply to the use of electricity in PtH systems and to the marketing of PtH heat.

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