Supplementary Information

1. Supplementary Text

Our supplementary text consists of four main sections:

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2. Steel Sample – Modelling assumptions for each company
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2. Supplemetary Figures and Tables

Supplementray Text

Steel Sample – Emission Factors

We applied the default EF derived from the literature as represented in *Supplementary Table 1*. The model inputs are highlighted in grey.

For the H2-DR process, studies estimated that the residual direct emissions from natural gas are around 0.04 tCO_2/t DRI [1] which would sum up to ~0.1 tCO_2/t steel for the H2-DRI-EAF process if we assumed a conversion factor of 1.2 tDRI/tcrude steel[2] and added the average value of 0.05 tCO_2/t steel for direct CO_2 emissions from scrap-EAF route applied above for the production of crude steel from DRI (and excluding DRI pellet production), as per the following calculation:

$$EF_{H2\ DRI-EAF} = \left[\left(0.04\ \frac{tCO2}{tDRI}\right) * 1.2 \frac{tDRI}{t\ crude\ steel}\right] + 0.05\ \frac{tCO2}{t\ crude\ steel} = 0.098\ \frac{tCO2}{t\ crude\ steel}$$

Other studies give lower estimates of ~0.05 tCO_2 per ton of steel produced by the H2-DRI-EAF route[3] (excluding DRI pellet production).

We applied the mean value of 0.075 tCO_2/t steel as default EF for the H2-DRI-EAF route, which is in line with a commonly assumed emission reduction potential of >95% that H2-DRI-EAFcould realize compared to the BF-BOF route[3], when taking into account our global average EF for the BF-based integrated route stated above (2.31 tCO_2/t steel).

For the natural gas-based DRI-BOF production route proposed by thyssenkrupp, we assumed a conversion factor of 1.2 tDRI/tcrude steel[2] and derived the following default EF based on the mean values from the literature illustrated in *Table* 2 below:

$$EF_{natural-ga\ \ DRI-BOF} = \left[\left(0.61\ \frac{tCO2}{tDRI}\right) * 1.2 \frac{tDRI}{t\ crude\ steel}\right] + 0.2\ \frac{tCO2}{t\ crude\ steel} = 0.932\ \frac{tCO2}{t\ crude\ steel}$$

To ensure consistency with the default EFs for H2-DRI from the selected studies[1,4] in *Supplementary Table 1*, we excluded direct emissions resulting from pre-processing (i.e., production of DRI pellets). For the H2-based DRI-BOF production route, the default EF is derived by the following equation:

$$EF_{H2\ DRI-BOF} = \left[\left(0.04\ \frac{tCO2}{tDRI}\right) * 1.2 \frac{tDRI}{t\ crude\ steel}\right] + 0.2\ \frac{tCO2}{t\ crude\ steel} = 0.248\ \frac{tCO2}{t\ crude\ steel}$$

Steel Sample – Modelling Assumptions for all 10 Sample Companies

1 ArcelorMittal

Reported capacity

All reported steel plants are covered in our modelling. The company reports an "Achievable Capacity" figure (82.7 MTPA in 2021) and it is unclear if this figure includes the capacity of the two JVs AM Italia (11.5 MTPA, 40% equity stake) as well as AG der Dillinger Hüttenwerke Dillingen steel plant (2.76 MTPA, 33%) or not, and/or if the company applies an utilization rate to the total nominal installed crude steel capacity to derive the "Achievable Capacity" figure. GEM derived crude steel capacity for 2021 is substantially higher (101.5 MTPA) than the reported "Achievable Capacity" figure (82.7 MTPA).

Production technology assumptions

AM/NS India includes natural gas-based MIDREX DRI shaft furnaces[1] as part of the DRI-EAF production route[2] and not coal gasification-based DRI or coal-based rotary kilns which are common to many other DRI-based steel plants in India. The ArcelorMittal Acindar Villa Constitución steel plant also includes natural gas-based MIDREX DRI shaft furnaces.[3] ArcelorMittal Montreal steel plant (ArcelorMittal Canada 1 & 2) also includes natural gas-based MIDREX DRI shaft furnaces.[4] ArcelorMittal Hamburg steel plant also includes natural gas-based MIDREX DRI shaft furnaces.[5] ArcelorMittal Lázaro Cárdenas steel plant also includes natural gas-based MIDREX DRI shaft furnaces.[6] ArcelorMittal Texas DRI plant also includes natural gas-based MIDREX DRI shaft furnaces.[7] ArcelorMittal Saldanha Steel Works also includes natural gas-based MIDREX DRI shaft furnaces.[8]ArcelorMittal Vanderbijlpark Steel Works includes coal-based DRI with six rotary kilns[9] feeding into BF units.

Bosnia and Herzegovina. For ArcelorMittal Zenica steel plant, we assumed a split of 0.8 MTPA scrap-EAF and 1.140 MTPA BF-BOF production capacity since the company lists the plant as "Mini Mill/Integrated" in its disclosure.[10]

[1] https://www.midrex.com/wp-content/uploads/Midrex-Plants-Sheet2023.pdf
[2] AM/NS India Climate Action Report 2024, p. 5 (https://www.amns.in/storage/Reports/AMNS-Climate-Action-Report-2024.pdf)
[3] https://www.midrex.com/wp-content/uploads/Midrex-DFM-1stQtr2022-Final.pdf
[4] https://corporate.arcelormittal.com/media/news-articles/arcelormittal-successfully-tests-partial-replacement-of-natural-gas-with-green-hydrogen-to-produce-dri
[5] https://corporate.arcelormittal.com/climate-action/decarbonisation-technologies/hamburg-h2-working-towards-the-production-of-zero-carbon-emissions-steel-with-hydrogen
[6] https://www.midrex.com/wp-content/uploads/Midrex-Plants-Sheet2023.pdf
[7] https://www.midrex.com/wp-content/uploads/Midrex-Plants-Sheet2023.pdf
[8] https://www.midrex.com/wp-content/uploads/MidrexSTATSBook2022.pdf
[9] https://www.arcelormittalsa.com/Portals/0/Intro%20to%20Vanderbijlpark%20Works.pdf
[10] Fact Book 2023, p. 46 (https://corporate.arcelormittal.com/media/shgb4sw5/arcelor-mittal-fact-book-2023.pdf)

Brazil. For ArcelorMittal Monlevade steel plant, we assumed that the EAF expansion under construction will be part of the established integrated BF production process. Since information is not available stating if the new EAF will mostly be fed by iron from the BF or scrap, we assume an integrated BF-EAF production process because the company expands BF and sinter plant capacity at the same time.[11] Thus, we applied the default EF for the integrated BF-BOF route in Brazil. For ArcelorMittal Juiz de Fora steel plant, we assumed 0.36 MTPA BF-EAF (for which we applied the default EF for the integrated BF-BOF route in Brazil) and 0.74 MTPA scrap-EAF based on GEM data and company disclosure.[12]

Germany. For ArcelorMittal Duisburg steel plant, we assumed a steelmaking capacity of 1.3 MTPA BOF as the plant does not include any BF units but is supplied by pig iron from the nearby thyssenkrupp Europe plant.[13] We applied a default EF for BOF-based crude steel production (see *Table 2*). Based on GEM data, we assumed for ArcelorMittal Hamburg steel plant production route split of 0.6 MTPA natural gas-based DRI-EAF and 0.5 MTPA scrap-EAF production capacity at a total plant steel production capacity of 1.1 MTPA.[14]

India. AM/NS India (60% equity stake) uses natural gas-based MIDREX shaft furnaces[15] as part of the DRI-EAF production route[16] and not coal gasification-based DRI or coal-based rotary kilns which are common to many other DRI-based steel plants in India. The company did not provide information on the production route specific crude steel outputs at ArcelorMittal Nippon Steel India Hazira Plant. To model the split between DRI-EAF and BF-EAF production routes, we assumed that the total crude steel output of 9.6 MTPA provided by GEM is produced by 2.040 MTPA BF-EAF and 7.560 MTPA DRI-EAF production routes due to the fact that typically ~1.2 tonnes of DRI sponge iron is required to produce 1 tonne of crude steel.[2] For the integrated (BF-EAF) production process, we applied the EF of the integrated BF-BOF route as no production process specific emissions factor was available. As a result, we may overestimate the direct CO_2 emissions for this production process. We further assumed that the 7 MTPA BOF expansion (as stated in the GEM database) includes a BF capacity expansion at a similar rate since BF capacity expansion plans are detailed in company's environment impact assessment applications for the Hazira plant.[17]

Italy. With regards to ArcelorMittal Acciaierie d'Italia Taranto steel plant, the Government of Italy took control of the plant in February 2024 through placing the JV company (AM owned 40%) in "in a special form of insolvency proceedings (extraordinary administration)."[18] That is why we excluded the JV from the modelling for the years 2024-2050.

[11] AR2023 Form 20-F, p. 106 (https://corporate.arcelormittal.com/media/g30lvkqn/form-20f-2023.pdf)
[12] Fact Book 2023, p. 67 (https://corporate.arcelormittal.com/media/shgb4sw5/arcelor-mittal-fact-book-2023.pdf)
[13] Fact Book 2023, p. 46 (https://corporate.arcelormittal.com/media/shgb4sw5/arcelor-mittal-fact-book-2023.pdf)
[14] https://hamburg.arcelormittal.com/Ueber-uns/
[15] https://www.midrex.com/wp-content/uploads/Midrex-Plants-Sheet2023.pdf
[16] AM/NS India Climate Action Report 2024, p. 5 (https://www.amns.in/storage/Reports/AMNS-Climate-Action-Report-2024.pdf)
[17] https://www.amns.in/storage/statutory-documents/October2022/6GnmFvhzMscsSdpEev87.pdf
[18] AR2023 Form 20-F, p. 104 (https://corporate.arcelormittal.com/media/g30lvkqn/form-20f-2023.pdf)

Mexico. To model the split between natural gas-based DRI-EAF and BF-BOF production routes for ArcelorMittal Lázaro Cárdenas steel plant, we assumed that the total crude steel output of 6.4 MTPA (provided by GEM) is produced by 2.4 MTPA BF-BOF[19] and 4 MTPA DRI-EAF[20] production routes.

South Africa. For ArcelorMittal Vanderbijlpark Steel Works, we assumed that the total crude steel output of 3.4 MTPA (GEM data updated by company disclosure; figure includes 3 MTPA BOF at Vanderbijlpark[21] and 0.4 MTPA EAF at Vereeniging[22]) is produced by BF-BOF while the coal-based 1.020 MTPA[23] DRI with six rotary kilns[24] feeding into the BF units.[25] We applied the EF for the BF-BOF production route which may lead to an underestimation of direct CO_2 emissions given that the preprocessing step in the DRI furnace is not taken into account. The plant used to have EAF units that were shut down indefinitely in 2012 due to environmental concerns.[26] ArcelorMittal Saldanha Steel Works is 0.8 MTPA natural gas-based DRI plant[27] that has been mothballed since Q2 2020.[28] In Nov 2023, AM announced to wind down operations at ArcelorMittal Newcastle Steel Works to negotiate with the Government of South Africa with regards to the future operations.[29]

Spain. For ArcelorMittal Asturias (Avilés) steel plant, we assumed a steelmaking capacity of 4.2 MTPA BOF as the plant does not include any BF units but is supplied by pig iron from the nearby ArcelorMittal Asturias (Gijón) steel plant.[30] We applied a default EF for BOF-based crude steel production (see Table 2).

USA. For ArcelorMittal Texas DRI plant, we assumed 1.6 MTPA (80% equity stake) of natural gas based DRI for which we applied a default EF for DRI-based iron production (see *Table 2*).

Historic and future UR

For the years 2020-2023, we took the total crude steel production reported by the company divided by the total equity share capacity as calculated based on our GEM model (assigned actual equity shares) because the company overinflates the reported nominal crude steel capacity figure (see above). For future UR, we took the average of the years 2020-2023 at the production route level and kept it constant until 2050.

[19] https://mexico.arcelormittal.com/nuestras-operaciones/aceros-largos?sc_lang=es
[20] https://mexico.arcelormittal.com/nuestras-operaciones/aceros-planos?sc_lang=es
[21] https://www.arcelormittalsa.com/Portals/0/Intro%20to%20Vanderbijlpark%20Works.pdf
[22] https://arcelormittalsa.com/Whoweare/WhatWeDo/SteelmakingandRolling.aspx
[23] https://www.midrex.com/wp-content/uploads/MidrexSTATSBook2022.pdf
[24] https://www.arcelormittalsa.com/Portals/0/Intro%20to%20Vanderbijlpark%20Works.pdf
[25] https://arcelormittalsa.com/Whoweare/WhatWeDo/IronMaking.aspx
[26] https://www.arcelormittalsa.com/Portals/0/Mittal%20shuts%20Vanderbijl%20electric-arc%20furnace.pdf
[27] https://www.midrex.com/wp-content/uploads/MidrexSTATSBook2022.pdf
[28] AR2023 Form 20-F, p. 101 (https://corporate.arcelormittal.com/media/g30lvkqn/form-20f-2023.pdf)
[29] AR2023 Form 20-F, p. 101 (https://corporate.arcelormittal.com/media/g30lvkqn/form-20f-2023.pdf)
[30] Fact Book 2023, p. 46 (https://corporate.arcelormittal.com/media/shgb4sw5/arcelor-mittal-fact-book-2023.pdf)

Ukraine. For ArcelorMittal Kryvyi Rih steel plant, we assumed that the capacity utilization rate for the entire integrated plant (8 MTPA BF-BOF) is 30% since the start of the Ukraine conflict as disclosed by the company.[31] This is in line with the substantially reduced actual crude steel production output of this plant since 2022.

We modelled the production capacity changes under the BAU and Stated TP scenarios as follows:

BAU scenario

Brazil

- ArcelorMittal Monlevade steel plant:
  - +1.2 MTPA BF expansion under construction and to come online by 2026. + 1.0 MTPA EAF expansion under construction and to come online by 2026.[32] Since information is not available if the new EAF will be fed by iron from the BF or scrap, we assume an integrated BF-EAF production process.

Luxembourg

- ArcelorMittal Esch-Belval steel plant:
  - +0.25 scrap EAF expansion to replace the old (1 MTPA) EAF with a new 1.25 MTPA EAF by 2025.[33]

Spain

- ArcelorMittal Asturias (Gijón) steel plant DRI and EAF expansion:
  - +1.1 MTPA EAF expansion under construction to come online by 2026[34]. Plan to establish a 2.3 MTPA DRI plant[35] but those may be delayed while importing green DRI from overseas.[36]

South Africa

- ArcelorMittal Newcastle Steel Works transition (EAF addition): Since the company announced plans to wind down the plant in late 2023 and is in discussions with the South African government as to whether the latter can provide government support, we excluded this plant from our modelling from 2025 onwards.[37]

[31] AR2023 Form 20-F, p. 101 (https://corporate.arcelormittal.com/media/g30lvkqn/form-20f-2023.pdf)
[32] https://corporate.arcelormittal.com/media/zsmpkwx2/arcelormittal-factbook-2023-web_interactive_april-30th.pdf, p. 19.
[33] https://luxembourg.arcelormittal.com/en/news-and-media/news/67-million-euros-in-a-new-electric-arc-furnace-at-its-belval-site-with-the
[34] https://corporate.arcelormittal.com/media/news-articles/arcelormittal-starts-the-construction-of-an-electric-arc-furnace-at-its-gijon-plant
[35] https://corporate.arcelormittal.com/media/press-releases/arcelormittal-publishes-second-group-climate-action-report
[36] https://www.hydrogeninsight.com/industrial/green-hydrogen-is-too-expensive-to-use-in-our-eu-steel-mills-even-though-weve-secured-billions-in-subsidies/2-1-1601199
[37] "On November 28, 2023, ArcelorMittal South Africa announced its plans to wind down its Newcastle works and the broader long steel products business subject to due diligence and consultation processes. Since then, the Company has been in discussions with government representatives to determine the extent of state support that

AM/NS India (60% equity stake):

- +2.8 MT BF-BOF at ArcelorMittal Nippon Steel Paradip Steel Plant to come online in 2029 (total + 7MT greenfield plant)[38]
- +5.6 BF-BOF at ArcelorMittal Nippon Steel Kendrapara plant to come online in 2028 (total +14 MT greenfield plant)[39]

Hazira plant

- +2.8 MT BF-BOF (+6 MT in total) at ArcelorMittal Nippon Steel India Hazira Plant BF and BOF expansion (I)[40]
- +3.36 MT BF-BOF (+8.4 MT in total) at ArcelorMittal Nippon Steel India Hazira Plant BF and BOF expansion (II) will come online in 2029.[41] For ArcelorMittal Nippon Steel India Hazira Plant BF and BOF expansion (II), we assumed BF-BOF technology as no other information was stated.

Stated TP scenario

The stated TP of ArcelorMittal steel only refers to its operations in specific regions (mostly Europe and North America) while the company does not disclose any transition plan for its operations in India via the AM/NS JV (60% equity share) which the company plans to expand from 5.9 MTPA BF-EAF and natural gas DRI-EAF to over 27.7 MTPA BF-BOF, BF-EAF, and natural gas DRI-EAF production capacity by 2030.[42] The stated TP includes proposed technology changes in the form of switching from BF-BOF production to scrap-EAF and (natural gas and later green H2 based) DRI-EAF production routes.

Importantly, to ensure consistency with the overall methodology applied here, we took at face value the TP stated in the company's official disclosures to utilize green H2-DRI despite the recent statements in May 2024 of company officials to the contrary with regards to the economic viability of green H2-DRI in Europe.[43] However, the modelling could be easily adjusted to use the EF for natural gas based DRI-EAF instead.

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could be provided to mitigate or prevent the closure of these operations." AR2023 Form 20-F, p. 101 (https://corporate.arcelormittal.com/media/g30lvkqn/form-20f-2023.pdf);

[38] https://corporate.arcelormittal.com/media/ld2hgpky/4q-23-roadshow-deck_feb.pdf, p. 22.

[39] https://corporate.arcelormittal.com/media/ld2hgpky/4q-23-roadshow-deck_feb.pdf, p. 22.

[40] https://www.nipponsteel.com/en/news/20220928_200.html

[41] https://corporate.arcelormittal.com/media/ld2hgpky/4q-23-roadshow-deck_feb.pdf, p. 22. Plan to increase total capacity of Hazira plant to 24 MT, which would mean that the second expansion will be around 8.4 MT, which we assumed here to be the case.

[42] AR2023 Form 20-F (https://corporate.arcelormittal.com/media/g30lvkqn/form-20f-2023.pdf); Second Climate Action Report (https://corporate-media.arcelormittal.com/media/ob3lpdom/car_2.pdf); Climate Action in Europe Report (https://corporate-media.arcelormittal.com/media/yw1gnzfo/climate-action-in-europe.pdf); Fact Book 2023 (https://corporate.arcelormittal.com/media/shgb4sw5/arcelor-mittal-fact-book-2023.pdf); AM/NS India Climate Action Report 2024 (https://www.amns.in/storage/Reports/AMNS-Climate-Action-Report-2024.pdf); ArcelorMittal Deutschland, Nachhaltigkeitsbericht 2022, p. 12 (https://germany.arcelormittal.com/icc/arcelor/med/d3b/d3b1466d-cdce-a81d-ebcc-c970b325aa0d,11111111-1111-1111-1111-111111111111.pdf)

[43] https://gmk.center/en/news/green-hydrogen-is-too-expensive-for-arcelormittal-europes-plants-ceo/

We modelled the following changes to the production asset base:

Capacity substitution by switching from BF-BOF to scrap-EAF / DRI-EAF

Belgium

- ArcelorMittal Gent steel plant (DRI-EAF addition): announced +2.5 MTPA DRI-EAF plant transition from BF-BOF to DRI-EAF production route to begin construction and come online by 2030 as stated by the company. Construction has not started yet, but letter of intent signed with Government.[44]
    - AM also announced to shut down BF "A" as it ramps up production from DRI plant after 2030 "after which blast furnace A will be closed as it reaches the end of its life."[45]
    - We modelled +2.5 MTPA DRI-EAF from 2030 and phase-out of BF "A" (-2.7MTPA) in 2030, while BF "B" (relined in 2021) will continue to be operated at with a BF-BOF capacity of 2.3 MTPA, resulting in a lower total plant capacity of 4.8 MTPA. As the company stated the aim to use green hydrogen but did not give a start year for H2-DRI-EAF, we assumed that green H2 will be available from 2030 (see *Methods*).

Canada

- ArcelorMittal Dofasco steel plant transition (DRI-EAF addition): announced +2.4 MTPA DRI-EAF plant transition to begin construction and come online by 2028 as stated by the company.[46] The company does not state the objective to use H2-DRI-EAF[47], which is why we applied the default EF for the use of natural gas as input into the DRI. Since the company did not state the objective to phase out BF production capacity completely, we assumed capacity substitution for 2.4 MTPA BF-BOF, and that at least one BF unit will continue to be operated after 2030 (1.65 MTPA BF-EAF which we modelled by applying the default EF for the BF-BOF production route) to keep the total plant capacity constant (4.050 MTPA).

France

- ArcelorMittal Dunkerque steel plant transition (DRI and EAF addition): announced +2.5 MTPA DRI-EAF plant transition from BF-BOF to DRI-EAF production route to begin construction and come online by 2027 as stated by the company. Since the company stated that 2 out of 3 BF units will be phased out by 2030 but did not state that BF units would be

[44] https://belgium.arcelormittal.com/en/arcelormittal-signs-letter-of-intent-with-the-governments-of-belgium-and-flanders-supporting-e1-1-billion-investment-in-decarbonisation-technologies-at-its-flagship-gent-plant/
[45] https://belgium.arcelormittal.com/en/arcelormittal-signs-letter-of-intent-with-the-governments-of-belgium-and-flanders-supporting-e1-1-billion-investment-in-decarbonisation-technologies-at-its-flagship-gent-plant/
[46] https://corporate.arcelormittal.com/media/press-releases/arcelormittal-decarbonisation-project-in-hamilton-canada-confirmed-with-the-announcement-of-a-cad-500m-investment-by-the-government-of-ontario
[47] https://corporate.arcelormittal.com/media/press-releases/arcelormittal-decarbonisation-project-in-hamilton-canada-confirmed-with-the-announcement-of-a-cad-500m-investment-by-the-government-of-ontario

phased out entirely, we assumed that the remaining BF "4"[48] (3.7 MTPA) would feed into the remaining BOF units.[49]

  - Based on GEM data and disclosure information, we modelled the entire plant as 2.5 MTPA natural gas-based DRI-EAF, 2.0 MTPA scrap-EAF, and 2.25 MTPA BF-BOF by 2027 at an unchanged total crude steel capacity of 6.75 MTPA (EAF). As the company stated the aim to use green hydrogen but did not give a start year for H2-DRI-EAF, we assumed that green H2 will be available from 2030 (see *Methods*).

- ArcelorMittal Méditerranée Fos sur Mer steel plant transition (EAF addition):
  - +2.0 MTPA EAF announced and assumed to come online by 2027. One BF unit to be phased out by 2030 as per company announcement.[50] We assumed that the production capacity of the entire plant at 4.0 MTPA would be 2.0 MTPA BF-EAF and 2.0 MTPA scrap-EAF from 2030 onwards, as the company does not state to phase out BF units entirely but states a plan to increase the use of scrap.[51] For the BF-EAF production route, we applied the default EF for the BF-BOF production route in France.

Germany

- ArcelorMittal Bremen steel plant transition (DRI-EAF addition):
  - +1.75 MTPA DRI-EAF plant expansion announced but not under construction yet.
  - We modelled +1.75 MTPA DRI- EAF plant to come online by 2030[52] (as stated in Climate Action Report) and phase-out of BF unit #3 (1.25 MTPA) by 2030. The total plant capacity remains 3.4 MTPA with the BF-BOF route covering the remaining 1.65 MTPA of production capacity as per company disclosure.[53] As the company stated the aim to use green hydrogen but did not give a start year for H2-DRI-EAF, we assumed that green H2 will be available from 2030 (see *Methods*).

- AG der Dillinger Hüttenwerke Dillingen steel plant transition (33.4% equity share):
  - We modelled currently announced +1.75 MTPA natural gas based DRI-EAF to come online by 2027 as capacity substitution for one BF unit which is retired early by 2027. Construction is due to start in 2024. The remaining BF-BOF capacity will run in parallel to the new DRI-EAF process.[54,55] As the company stated the aim to

[48] https://eurometal.net/arcelormittal-dunkirk-to-operate-only-one-blast-furnace/
[49] https://corporate.arcelormittal.com/media/press-releases/arcelormittal-accelerates-its-decarbonisation-with-a-1-7-billion-investment-programme-in-france-supported-by-the-french-government
[50] https://corporate.arcelormittal.com/media/press-releases/arcelormittal-accelerates-its-decarbonisation-with-a-1-7-billion-investment-programme-in-france-supported-by-the-french-government
[51] https://corporate.arcelormittal.com/media/press-releases/arcelormittal-accelerates-its-decarbonisation-with-a-1-7-billion-investment-programme-in-france-supported-by-the-french-government
[52] See Second Climate Action Report (https://corporate-media.arcelormittal.com/media/ob3lpdom/car_2.pdf), p 17.
[53] ArcelorMittal Bremen, Webinar Presentation, p. 12 (https://germanyworks.com/fileadmin/webinars/downloads/221007_HY5_DigitalBriefing_ArcelorMittal_JuergenFries.pdf)
[54] https://en.dillinger.de/news/press-releases/supervisory-boards-decide-green-steel-will-be-produced-in-the-saar-region/?id=6995
[55] https://www.pure-steel.com/power4steel/

use green hydrogen[56] but did not give a start year for H2-DRI-EAF, we assumed that green H2 will be available from 2030 (see *Methods*).

- ArcelorMittal Duisburg steel plant transition (EAF addition):
  - We modelled a transition from BOF to EAF based crude steel production. Expansion of +1 MTPA EAF has been announced without start date[57], which is we assumed the plant comes online by 2029. Total crude steel capacity is reduced from 1.3 to 1.0 MTPA (as no other information was available). The plant will be supplied by DRI/HBI from the Hamburg plant.

- ArcelorMittal Eisenhüttenstadt steel plant transition (DRI-EAF addition):
  - +1.75 MTPA DRI-EAF plant expansion announced but not under construction yet.
    - We modelled +1.75 MTPA DRI- EAF plant to come online by 2030[58] (as stated in Climate Action Report) and phase-out of the BF unit[59] as well as the 2.4 MTPA BF-BOF production route at the plant. As the company stated the aim to use green hydrogen but did not give a start year for H2-DRI-EAF, we assumed that green H2 will be available from 2030 (see *Methods*).

- ArcelorMittal Hamburg steel plant:
  - Announced pilot plant of 0.1 MTPA H2-DRI unit[60] to come online by 2026 which will be ramped up to 0.6 MTPA by 2030. As the company stated the aim to use green hydrogen but did not give a start year for H2-DRI-EAF, we assumed that green H2 will be available from 2030 (see *Methods*).

Luxembourg

- ArcelorMittal Esch-Belval steel plant:
  - +0.25 scrap EAF expansion at ArcelorMittal Esch-Belval steel plant to replace the old (1 MTPA) EAF with a new 1.25 MTPA EAF.[61]

Spain

- ArcelorMittal Asturias (Gijón) steel plant DRI and EAF expansion:
  - +1.1 MTPA EAF expansion under construction to come online by 2026. We treated this as capacity addition until the DRI plant comes online by 2029 (see below).

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[56] https://en.dillinger.de/news/press-releases/milestone-on-the-path-to-green-transformation/?id=7038

[57] ArcelorMittal Deutschland, Nachaltigkeitsbericht 2022, p. 12 (https://germany.arcelormittal.com/icc/arcelor/med/d3b/d3b1466d-cdce-a81d-ebcc-c970b325aa0d,11111111-1111-1111-1111-111111111111.pdf)

[58] See Second Climate Action Report (https://corporate-media.arcelormittal.com/media/ob3lpdom/car_2.pdf), p 17.

[59] ArcelorMittal Bremen, Webinar Presentation, p. 12 (https://germanyworks.com/fileadmin/webinars/downloads/221007_HY5_DigitalBriefing_ArcelorMittal_JuergenFries.pdf)

[60] https://corporate.arcelormittal.com/climate-action/decarbonisation-technologies/hamburg-h2-working-towards-the-production-of-zero-carbon-emissions-steel-with-hydrogen

[61] https://luxembourg.arcelormittal.com/en/news-and-media/news/67-million-euros-in-a-new-electric-arc-furnace-at-its-belval-site-with-the

- Plan to establish a +2.3 MTPA DRI plant[62] but those may be delayed while importing green DRI from overseas.[63] We modelled +2.3 MTPA DRI plant to come online by 2029 (since construction has not started) and phase-out of 1.2 MTPA BF-BOF production route at the plant.[64] However, because the company did not state that it aims to phase-out all BF units at Gijón, we assumed that one BF unit will be kept in operation to supply the remaining BOF production units at Aviles plant (see below). As the company stated the aim to use green hydrogen but did not give a start year for H2-DRI-EAF, we assumed that green H2 will be available from 2030 (see *Methods*).

ArcelorMittal Asturias (Avilés) steel plant

- Plant is not explicitly included in Stated TP. That is why we assumed that the company will retain 50% of its current BOF based crude steel making capacity (2.1 MTPA) at Aviles to the extent that it can produce crude steel from the pig iron supplied by the remaining BF at Gijón. To avoid double counting between the Avilés and the Gijón plant, we accounted for the entire 2.1 MTPA BF-BOF based crude steel production at Avilés.

ArcelorMittal Sestao steel plant (Bilbao)

- The company plans to supply Sestao with 1 MT DRI from Gijón DRI unit[65] while stating that the targeted crude steel output is 1.6 MTPA in total[66] once the Gijón DRI unit is operational. We assumed that Sestao's steel output by 2029 would be 1 MT DRI-EAF and 0.6 MTPA scrap-EAF as the company stated the aim to increase the use of scrap.[67] To avoid double counting between the Sestao and the Gijón plant, we reduced the scrap-EAF capacity at Sestao from 2 MTPA to 1 MTPA by 2029 and accounted for the entire DRI-EAF production route at Gijón (2.3 MTPA), which includes the EAF-based crude steel production of the 1 MT DRI that the company aims to ship to Sestao.

South Africa

- ArcelorMittal Vanderbijlpark Steel Works transition (EAF addition): We assumed that the 1.7 MTPA EAF expansion will come online by 2030 at full capacity substitution for existing BOF capacity.[68] Additionally, the company plans to phase out BF C by 2030, while relining and upgrading BF D between 2027-2030 for hydrogen injection. Since the

[62] https://corporate.arcelormittal.com/media/press-releases/arcelormittal-publishes-second-group-climate-action-report

[63] https://www.hydrogeninsight.com/industrial/green-hydrogen-is-too-expensive-to-use-in-our-eu-steel-mills-even-though-weve-secured-billions-in-subsidies/2-1-1601199

[64] "The construction of the DRI and EAF units will transition the Gijón plant away from BF-BOF steelmaking to DRI-EAF production, which generates a significantly lower carbon footprint." See Second Climate Action Report, p 16 (https://corporate-media.arcelormittal.com/media/ob3lpdom/car_2.pdf)

[65] https://corporate.arcelormittal.com/media/press-releases/arcelormittal-sestao-to-become-the-world-s-first-full-scale-zero-carbon-emissions-steel-plant

[66] https://corporate.arcelormittal.com/climate-action/decarbonisation-investment-plans/spain-a-1-billion-investment-to-halve-our-carbon-emissions-and-create-the-world-s-first-full-scale-zero-carbon-emissions-steel-plant

[67] https://corporate.arcelormittal.com/media/press-releases/arcelormittal-sestao-to-become-the-world-s-first-full-scale-zero-carbon-emissions-steel-plant

[68] ArcelorMittal South Africa, Decarbonization Roadmap, 2023, p. 5 (https://arcelormittalsa.com/Portals/0/ArcelorMittal%20South%20Africa%20Decarbonisation%20Roadmap%20(January%202023)%20(2).pdf)

company also plans to increase the use of scrap, we modelled 1.7MTPA scrap-EAF production capacity from 2030 onwards. [69]

- ArcelorMittal Newcastle Steel Works transition (EAF addition): Since the company announced plans to wind down the plant in late 2023 and is in discussions with the South African government as to whether the latter can provide government support, we excluded the Stated TP information for this plant from our modelling.[70]

- ArcelorMittal Saldanha Steel Works: We assumed that the plant (currently mothballed) will resume operations and upgraded to H2-DRI-EAF by 2030.[71] As the company stated the aim to use green hydrogen but did not give a start year for H2-DRI-EAF, we assumed that green H2 will be available from 2030 (see *Methods*).

[69] ArcelorMittal South Africa, Decarbonization Roadmap, 2023, p. 4 (https://arcelormittalsa.com/Portals/0/ArcelorMittal%20South%20Africa%20Decarbonisation%20Roadmap%20(January%202023)%20(2).pdf)

[70] "On November 28, 2023, ArcelorMittal South Africa announced its plans to wind down its Newcastle works and the broader long steel products business subject to due diligence and consultation processes. Since then, the Company has been in discussions with government representatives to determine the extent of state support that could be provided to mitigate or prevent the closure of these operations." AR2023 Form 20-F, p. 101 (https://corporate.arcelormittal.com/media/g30lvkqn/form-20f-2023.pdf);

[71] ArcelorMittal South Africa, Decarbonization Roadmap, 2023, p. 8 (https://arcelormittalsa.com/Portals/0/ArcelorMittal%20South%20Africa%20Decarbonisation%20Roadmap%20(January%202023)%20(2).pdf)

2 Baoshan Iron & Steel

Reported capacity

All reported steel plants are covered in our modelling. Our capacity estimate based on GEM data is 52 MTPA in 2022 and thus lower than the total nominal crude steel capacity of 55 MTPA reported by the company in the 2023 CDP Report for the FY 2022.

Production technology assumptions

Since production route-specific information for its production plants was not disclosed by the company, we assumed that the company operates an integrated (BF-EAF) production process at Baoshan Iron and Steel Co., Ltd. (Baoshan Base) instead of a scrap-EAF based production process. For the integrated (BF-EAF) production process, we applied the EF of the integrated BF-BOF route as no production process specific emissions factor was available. As a result, we may overestimate the direct CO_2 emissions for this production process. For the DRI-EAF[72] at Baosteel Zhanjiang Iron & Steel Co., Ltd, we assumed a standard EF of 1.1 tCO2/t steel (natural gas based) before 2035, and the EF of the H2-DRI-EAF route (0.075 tCO_2/t steel) for the years 2035-2050.

Historic and future UR

For the years 2021 and 2022, we took the total crude steel production reported by the company in CDP reports divided by the total equity share capacity as calculated based on our GEM model (assigned actual equity shares). For the years 2020 and 2023, information on annual crude steel production output was not disclosed by the company. Worldsteel figures could not be used as those include only aggregated crude steel output figures for the parent company China Baowu Group Holdings. For the years 2020 as well as 2023-2050, we took the average of the years 2020-2023 at the production route level and kept it constant until 2050.[73]

We modelled the production capacity changes under the BAU and Stated TP scenarios as follows:

BAU scenario

- +1.8 MT H2-DRI-EAF[74] started operation at Baosteel Zhanjiang Iron & Steel Co., Ltd. in 2024 operated with natural gas until 2035, and with green hydrogen beyond 2035[75]. This is assumed to be a capacity substitution of existing BF-BOF capacity.[76]

[72] https://res.baowugroup.com/attach/2022/08/09/8ba72f8fe6084f20a52dbf5ac12d7d64.pdf
[73] Climate Action Report, p. 47 (https://res.baowugroup.com/attach/2022/08/09/8ba72f8fe6084f20a52dbf5ac12d7d64.pdf)
[74] https://res.baowugroup.com/attach/2022/08/09/8ba72f8fe6084f20a52dbf5ac12d7d64.pdf
[75] Climate Action Report 2022, p. 47 (https://res.baowugroup.com/attach/2022/08/09/8ba72f8fe6084f20a52dbf5ac12d7d64.pdf)
[76] https://res.baowugroup.com/attach/2023/07/21/982f05e8ceb54382b973f08af664226c.pdf

Stated TP scenario

The company's stated TP includes proposed technology changes in the form of switching from BOF-BF to scrap-EAF and (natural gas and later green H2 based) DRI-EAF production routes.

- +1.8 MT H2-DRI-EAF[77] started operation at Baosteel Zhanjiang Iron & Steel Co., Ltd. in 2024 operated with natural gas until 2035, and with green hydrogen beyond 2035[78]. This is assumed to be a capacity substitution of existing BF-BOF capacity.[79]
- +1 MT scrap-EAF announced to start operation in 2024, to increase to 2.3 MT scrap-EAF in 2030.[80] As the company did not disclose information if the EAF addition is a crude steel capacity addition or substitution of existing BF-BOF capacity, we assumed scrap-EAF based capacity substitution for existing BF-BOF capacity.

[77] https://res.baowugroup.com/attach/2022/08/09/8ba72f8fe6084f20a52dbf5ac12d7d64.pdf
[78] Climate Action Report 2022, p. 47 (https://res.baowugroup.com/attach/2022/08/09/8ba72f8fe6084f20a52dbf5ac12d7d64.pdf)
[79] https://res.baowugroup.com/attach/2023/07/21/982f05e8ceb54382b973f08af664226c.pdf
[80] Climate Action Report, p. 47 (https://res.baowugroup.com/attach/2022/08/09/8ba72f8fe6084f20a52dbf5ac12d7d64.pdf)

3 BlueScope Steel

Reported capacity

All reported steel plants are covered in our modelling. The EAF capacity expansion in the US at BlueScope North Star Steel plant became operational in 2022 and thus had to be removed from the production asset bases for the years 2020-2021. Our capacity estimate for 2021 based on GEM data (6 MTPA) approximately equals the reported capacity figure (6 MTPA).

Production technology assumptions

BlueScope New Zealand Steel Glenbrook includes coal-based DRI with four rotary kilns feeding into an oxygen converter.[81] As no other information was available, we applied the default EF of 3.1 tCO2/t steel for the coal-based DRI-BOF as well as the upgraded coal-based DRI-EAF route.

Historic and future UR

For the years 2020-2023, we took the total crude steel production reported by the company divided by the total equity share capacity as calculated based on our GEM model (assigned actual equity shares). For future UR, we took the average of the years 2020-2023 at the production route level and kept it constant until 2050.

We modelled the production capacity changes under the BAU and Stated TP scenarios as follows:

BAU scenario

- BF substitution at Port Kembla steel plant as BF Unit 5 (3 MT) is phased-out and Unit 6 (3 MT) will be relined and operated again (currently mothballed).[82]
    - This relining makes up AU$1.15bn / AU$1.9bn total CAPEX, while only AU$150 m will be spent on “climate projects”.[83]
- +0.650 coal-based DRI-EAF at BlueScope New Zealand Steel Glenbrook[84] currently under construction and to start operations in 2026[85]. Coal-based DRI-EAF capacity will substitute currently operated coal-based DRI-BOF capacity.[86]

[81] https://www.nzsteel.co.nz/new-zealand-steel/electric-arc-furnace/
[82] https://www.bluescope.com/content/dam/bluescope/corporate/bluescope-com/sustainability/documents/2023_BlueScope_Report_Sustainability_Report.pdf
[83] https://www.bluescope.com/content/dam/bluescope/corporate/bluescope-com/sustainability/documents/2023_BlueScope_Report_Sustainability_Report.pdf
[84] https://www.bluescope.com/content/dam/bluescope/corporate/bluescope-com/sustainability/documents/2023_BlueScope_Report_Sustainability_Report.pdf
[85] https://www.bluescope.com/content/dam/bluescope/corporate/bluescope-com/investor/documents/2023_BlueScope_EAF_Project_at_NZSteel_moves_to_execution.pdf
[86] https://www.nzsteel.co.nz/new-zealand-steel/electric-arc-furnace/

TP scenario

The company conducted a H2-DRI feasibility study and concluded that it will not go ahead with plans to utilize green H2 in the future[87], and the company also stated that it removed "Hydrogen electrolyser pilot plant at Port Kembla" and "Hydrogen blending project at Springhill" from its project pipeline[88]. We modelled the following changes:

- BF substitution at Port Kembla steel plant as BF Unit 5 (3 MT) is phased-out and Unit 6 (3 MT) will be relined and operated again (currently mothballed).[89]
    - This relining makes up AU$1.15bn / AU$1.9bn total CAPEX, while only AU$150 m will be spent on "climate projects"![90]
- +0.650 coal-based DRI-EAF at BlueScope New Zealand Steel Glenbrook[91] currently under construction and to start operations in 2026[92]. Coal-based DRI-EAF capacity will substitute currently operated coal-based DRI-BOF capacity.[93]
- +0.5 MT scrap-EAF plant in the US currently announced and modeled to come online in 2029 (plant is included in GEM database and mentioned in the Climate Action Report)[94]. This is assumed to be a capacity addition (not substitution with existing BF-BOF capacity in Australia).

[87] https://www.bluescope.com/content/dam/bluescope/corporate/bluescope-com/sustainability/documents/2023_BlueScope_Report_Sustainability_Report.pdf
[88] See Investor Presentation 2023, p. 56 (https://www.bluescope.com/content/dam/bluescope/corporate/bluescope-com/investor/documents/2023_BlueScope_Presentation_Investor_Day_September.pdf)
[89] https://www.bluescope.com/content/dam/bluescope/corporate/bluescope-com/sustainability/documents/2023_BlueScope_Report_Sustainability_Report.pdf
[90] https://www.bluescope.com/content/dam/bluescope/corporate/bluescope-com/sustainability/documents/2023_BlueScope_Report_Sustainability_Report.pdf
[91] https://www.bluescope.com/content/dam/bluescope/corporate/bluescope-com/sustainability/documents/2023_BlueScope_Report_Sustainability_Report.pdf
[92] https://www.bluescope.com/content/dam/bluescope/corporate/bluescope-com/investor/documents/2023_BlueScope_EAF_Project_at_NZSteel_moves_to_execution.pdf
[93] https://www.nzsteel.co.nz/new-zealand-steel/electric-arc-furnace/
[94] Climate Action Report 2021, p. 40 (https://www.bluescope.com/content/dam/bluescope/corporate/bluescope-com/sustainability/documents/2021_BlueScope_Report_Climate_Action_Report.pdf), https://www.bluescope.com/content/dam/bluescope/corporate/bluescope-com/investor/documents/2023_BlueScope_Presentation_Investor_Day_September.pdf

4 China Steel

Reported capacity

All reported steel plants are covered in our modelling. The company does not report exact capacity figures and apparently also does not include the 25% equity share in the Formosa Ha Tinh Steel plant JV in Vietnam. That is why the disclosed nominal crude steel production capacity of 16 MTPA for 2022[95] is lower than our asset base model based on GEM data (18 MTPA).

Production technology assumptions

It is assumed that the company currently uses the BF-EAF route (and not scrap-EAF) at the DSC plant.[96,97] For the integrated (BF-EAF) production process, we applied the EF of the integrated BF-BOF route as no production process specific emissions factor was available. As a result, we may overestimate the direct CO_2 emissions for this production process.

Historic and future UR

The company did not disclose aggregated crude steel production output figures. For the years 2020-2023, we took the total crude steel production reported by worldsteel divided by the total equity share capacity as calculated based on our GEM model (assigned actual equity shares). Since worldsteel figures do not include production output from minority equity share holdings (<30%), the reported crude steel production figures will most likely not include the crude output from CSC's JV in Vietnam. For future UR, we took the average of the years 2020-2023 at the production route level and kept it constant until 2050.

We modelled the production capacity changes under the BAU and Stated TP scenarios as follows:

BAU scenario

- + 10 MT BF-BOF capacity at Formosa Ha Tinh Steel plant (currently announced) to come online in 2025 and 2035.

TP scenario

- The company did not state additional asset-specific upgrades or newly build plants in CDP reports or corporate disclosure.[98,99, 100,101] While the company stated some broad, long-term ambitions (e.g., "In the long-term, we will develop carbon capture and storage

[95] Investor Presentation, p. 45 (https://www.csc.com.tw/csc_e/ss/pst/pdf/2023Dec21.pdf)
[96] https://www.dragonsteel.com.tw/en/abo/about.html
[97] CDP Report 2022 (C-ST4.9) indicates that the company does not use scrap-EAF but BF-EAF route.
[98] https://www.csc.com.tw/csc_e/ss/pst/pdf/2023Dec21.pdf
[99] https://www.dragonsteel.com.tw/en/abo/about.html
[100] https://www.csc.com.tw/csc_e/ss/pst/pst_index.html#
[101] Sustainability Report 2022, p. 123-124 (https://www.csc.com.tw/csc_e/esg/pdf/hr-2022e.pdf)

and hydrogen energy smelting processes"[102]), none of those are associated with specific assets, production routes, or phase-out plans of existing BF-BOF assets, which is why we did not take them into account in our explicit modelling approach.

[102] Sustainability Report 2022, p. 13 (https://www.csc.com.tw/csc_e/esg/pdf/hr-2022e.pdf)

5 Nippon Steel

Reported capacity

All reported steel plants are covered in our modelling. The company overreports nominal crude steel production capacity because it accounts for 100% equity ownership for overseas JVs. For instance, the total nominal crude steel capacity of plants is reported (not the equity interest) for the JV with ArcelorMittal in India, for which Nippon reports a crude steel capacity of 9600 MTPA (100%) instead of 3840 (40%), which is Nippon's actual equity share of capacity in the JV company. The overseas capacity based on Nippon's actual equity shares according to our analysis of GEM data is 9.635 MT (as of 2022), whereas the overseas capacity based on 100% equity share ownership based on GEM data would be 19.943 MT (as of 2022). This is where most of the difference between the total crude steel capacity reported by Nippon (66 MTPA) and our capacity estimate (57.4 MTPA) comes from.

Production technology assumptions

For Nippon Kansai Works (Wakayama Area, Wakayama) steel plant as well as for North Nippon Muroran Works steel plant, we assumed that the EAF plant is supplied by the iron output from a BF unit (and not scrap) as the company nor GEM do state otherwise. The Usiminas Cubatão steel plant in Brazil as well as the Nippon Kyushu Works (Yawata Area, Kokura) steel plant are listed by GEM as mothballed as of 2023 and were not included in the modelling. The Nippon Setouchi Works (Kure Area) steel plant in Japan was closed in 2021 and was excluded from the modelling for the rest of the scenario horizon.

AM/NS India (40% equity stake) uses natural gas-based MIDREX shaft furnaces[103] as part of the DRI-EAF production route[104] and not coal gasification-based DRI or coal-based rotary kilns which are common to many other DRI-based steel plants in India. The company did not provide information on the production route specific crude steel outputs at ArcelorMittal Nippon Steel India Hazira Plant. To model the split between DRI-EAF and BF-EAF production routes, we assumed that the total crude steel output of 9.6 MTPA provided by GEM is produced by 2.040 MTPA BF-EAF and 7.560 MTPA DRI-EAF production routes due to the fact that typically ~1.1 t DRI sponge iron is required to produce 1 t of crude steel. For the integrated (BF-EAF) production process, we applied the EF of the integrated BF-BOF route as no production process specific emissions factor was available. As a result, we may overestimate the direct CO_2 emissions for this production process. We further assumed that the 7 MTPA BOF expansion (as stated in the GEM database) includes a BF capacity expansion at a similar rate since BF capacity expansion plans are detailed in company's environment impact assessment applications for the Hazira plant.[105]

[103] https://www.midrex.com/wp-content/uploads/Midrex-Plants-Sheet2023.pdf
[104] AM/NS India Climate Action Report 2024, p. 5 (https://www.amns.in/storage/Reports/AMNS-Climate-Action-Report-2024.pdf)
[105] https://www.amns.in/storage/statutory-documents/October2022/6GnmFvhzMscsSdpEev87.pdf

Historic and future UR

For the years 2020-2022, we took the total crude steel production reported by the company divided by the total equity share capacity as calculated based on our GEM model (assigned actual equity shares) because the company overinflates the reported nominal crude steel capacity figure (see above). For the year 2023, we took the total crude steel production reported by the World Steel Association (as company disclosure was not available). For future UR, we took the average of the years 2020-2023 at the production route level and kept it constant until 2050.

We modelled the production capacity changes under the BAU and Stated TP scenarios as follows:

BAU scenario

Nippon Steel Company (Japan)

- +0.7 MT EAF in 2022 at Nippon Setouchi Works (Hirohata Area) steel plant[106]
- We took into account announced BF closures in Japan: early retirement of 5.37 MTPA BF at Kashima No. 3 by 2025[107]:
  - "Shut down facilities including one BF (Kashima No. 3) in accordance with the roadmap for the structural measures, and consolidate production into competitive facilities" [108], "the No. 3 blast furnace and related facilities at the East Nippon Works Kashima Area will also be shut down"[109]
  - We assumed that both BF units which have the same iron capacity as per GEM contribute 50% each to the total crude steel output of the plant.

Overseas operations

AM/NS India (40% equity stake):

- +2.8 MT BF-BOF at ArcelorMittal Nippon Steel Paradip Steel Plant to come online in 2029 (total + 7MT greenfield plant)[110]
- +5.6 BF-BOF at ArcelorMittal Nippon Steel Kendrapara plant to come online in 2028 (total +14 MT greenfield plant)[111]

Hazira plant

- +2.8 MT BF-BOF (+7 MT in total) at ArcelorMittal Nippon Steel India Hazira Plant BF and BOF expansion (I)[112]

[106] https://www.nipponsteel.com/en/ir/library/pdf/20220510_600.pdf
[107] Integrated Report 2023, p. 25. (https://www.nipponsteel.com/en/ir/library/pdf/nsc_en_ir_2023_a3.pdf)
[108] Integrated Report 2023, p. 22. (https://www.nipponsteel.com/en/ir/library/pdf/nsc_en_ir_2023_a3.pdf)
[109] Integrated Report 2023, p. 25. (https://www.nipponsteel.com/en/ir/library/pdf/nsc_en_ir_2023_a3.pdf)
[110] https://corporate.arcelormittal.com/media/ld2hgpky/4q-23-roadshow-deck_feb.pdf, p. 22.
[111] https://corporate.arcelormittal.com/media/ld2hgpky/4q-23-roadshow-deck_feb.pdf, p. 22.
[112] https://www.nipponsteel.com/en/news/20220928_200.html

- +3.36 MT BF-BOF (+8.4 MT in total) at ArcelorMittal Nippon Steel India Hazira Plant BF and BOF expansion (II) will come online in 2029.[113] For ArcelorMittal Nippon Steel India Hazira Plant BF and BOF expansion (II), we assumed BF-BOF technology as no other information was stated.

Stated TP scenario

The stated TP of Nippon steel only refers to its operations in Japan while the company does not disclose any transition plans for its overseas operations (e.g., for the AM/NS JV in India). [114] The stated TP includes the following technology changes: (1) switch from BF-BOF production to scrap-EAF production route, and (2) introduction of H2-DRI-EAF production. We excluded the proposed plans for introducing "COURSE50" / "Super COURSE50" at BF units from our modelling because this technology is based on hydrogen injection at existing high emitting BF units and thus represents a fuel (and not technology) change (see *Methods*). We modelled the following changes to the production asset base:

Transition plan:

1. **High-grade steel production in large size EAF**
   - Setouchi Works Hirohata Area:
     - +0.7 MT EAF in 2022 at Nippon Setouchi Works (Hirohata Area) steel plant[115]
     - Small scale study (2023) -> "large scale EAF" expansion by 2030: Since information on EAF capacity was not available, we assumed that the company constructs another EAF with the same capacity (0.7 MT) as the previous EAF at the same plant and starts operations in 2030 as stated in the Integrated Report 2023.[116] We further assumed full capacity substitution with the existing BOF capacity, which means that the latter is reduced by 0.7 MT in 2030.
   - Kyushu Works Yawata Area:
     - Conversion of BF at Yawata No. 4 to EAF by 2030[117]
     - small scale study (2023) -> "large scale EAF" conversion by 2030: Since information on EAF capacity was not available, we assumed that the company constructs another EAF with the same capacity (0.7 MT) as the previous EAF at Setouchi Works Hirohata Area and starts operations in

[113] https://corporate.arcelormittal.com/media/ld2hgpky/4q-23-roadshow-deck_feb.pdf, p. 22. Plan to increase total capacity of Hazira plant to 24 MT, which would mean that the second expansion will be around 8.4 MT, which we assumed here to be the case
[114] Integrated Report 2023, p. 32 (https://www.nipponsteel.com/en/ir/library/pdf/nsc_en_ir_2023_a3.pdf); Sustainability Report 2023 (https://www.nipponsteel.com/en/csr/report/pdf/report2023en.pdf); Nippon Steel Group Medium to Long-Term Management Plan (https://www.nipponsteel.com/en/ir/library/pdf/20210305_200.pdf)
[115] https://www.nipponsteel.com/en/ir/library/pdf/20220510_600.pdf
[116] Integrated Report 2023, p. 32. (https://www.nipponsteel.com/en/ir/library/pdf/nsc_en_ir_2023_a3.pdf)
[117] Integrated Report 2023, p. 32. (https://www.nipponsteel.com/en/ir/library/pdf/nsc_en_ir_2023_a3.pdf)

2030 as stated in the Integrated Report 2023.[118] We assumed that the BF No. 4 is phased out by 2030.

2. Hydrogen direct reduction of iron

The company states that H2-DRI-EAF will be implemented after 2040[119] and the plan to "build a small furnace in the Hasaki R&D Center and start experiments in fiscal 2025" …"Start demonstration test on expanded scale" by 2027…"Then, *by 2050*, we aim to solve issues such as utilization of low-grade iron ore and conversion of reduction material from natural gas to hydrogen, and *to commercialize a direct hydrogen reduction reactor* using low-grade iron ore from Australia and other countries as feedstock" (the authors' italics). [120] In other words, the company states the plan to develop and implement one H2 DRI-EAF plant at commercial scale after 2040. The company did not state more specific plans which plants will be switched to H2-DRI-EAF in the major disclosure documents (nor any additional BF-BOF phase out plants at the asset or corporate level). Based on the company's stated plans to build a DRI demonstration plant at Kyushu, we assumed that the company switches from the BF-BOF to the H2-DRI-EAF production process at Kyushu steel works by 2045.[121] This involves the early retirement of BF unit 4 at Kyushu steel works in 2044.

[118] Integrated Report 2023, p. 32. (https://www.nipponsteel.com/en/ir/library/pdf/nsc_en_ir_2023_a3.pdf)
[119] Integrated Report 2023, p. 3, see the timeline as part of the "Roadmap to achieve the Carbon Neutral" (https://www.nipponsteel.com/en/ir/library/pdf/nsc_en_ir_2023_a3.pdf)
[120] Integrated Report 2023, p. 32. (https://www.nipponsteel.com/en/ir/library/pdf/nsc_en_ir_2023_a3.pdf)
[121] Integrated Report 2023, p. 32. (https://www.nipponsteel.com/en/ir/library/pdf/nsc_en_ir_2023_a3.pdf)

6 POSCO

Reported capacity

All reported steel plants are covered in our modelling. The company disclosed a total crude steel production capacity figure for 2022 (44.6 MTPA) which is close to the aggregated capacity figure we retrieved from GEM (44.0 MTPA).[122]

Production technology assumptions

We assumed the entire POSCO Pohang steel plant is based on BF-BOF production route and thus disregarded the FINEX process at the plant because the resulting CO2 emissions are only marginally less than the BF-BOF production route (-3%)[5].

Although the HyREX DRI technology is planned to be a hydrogen fueled DRI coupled with an electric smelting furnace (ESF) to turn DRI into crude steel (H2-DRI-ESF)[123], we applied the EF of the H2-DRI-EAF production route (0.075 tCO_2/t steel) due to lack of specific information for the HyREX DRI technology.

Historic and future UR

The company disclosed steel production plant specific utilization rates in its annual reports for the years 2020-2022. For the year 2023, we took the total crude steel production reported by the company in its AR 2024[124] divided by the total equity share capacity as calculated based on our GEM model (assigned actual equity shares). For future UR, we took the average of the years 2020-2023 at the production route level and kept it constant until 2050.

We modelled the production capacity changes under the BAU and Stated TP scenarios as follows:

BAU scenario

- + 2.5 MTPA scrap-EAF at POSCO Gwangyang steel plant currently under construction to come online in 2026 (substituting for 2.5 MTPA BF-BOF capacity)[125]
- Announced +3.0 MTPA BF expansion at KS Posco Cilegon steel plant to come online in 2025 (start date given by GEM).

Stated TP scenario

[122] AR2023 (Form 20-F), p. 23 (https://www.posco-inc.com:4453/resource/v3/file/investor/2023Form20-F.pdf)
[123] https://www.posco.co.kr/homepage/docs/eng7/jsp/hyrex/#:~:text=Carbon%20Neutral%20HyREX&text=The%20conventional%20method%20for%20producing,Direct%20Reduced%20Iron%20(DRI).
[124] AR2024 (Form 20-F), https://www.sec.gov/ix?doc=/Archives/edgar/data/889132/000119312524119728/d721789d20f.htm
[125] AR2023 (Form 20-F), p. 63 (https://www.posco-inc.com:4453/resource/v3/file/investor/2023Form20-F.pdf)

The company's stated TP[126,127] includes proposed technology changes in the form of switching from BF-BOF production to scrap-EAF and (natural gas and later green H2 based) DRI-ESF production routes. More specifically, the company aims to increase EAF capacity as well as to invest in a demonstration plant based on a hydrogen based DRI process (HyREX), and to expand H2 based DRI-EAF production in the future.[128] The aim is to reach carbon neutrality by 2050 through emission reductions at production sites as well as "avoided emissions".[129] Importantly, the stated TP does not explicitly cover the highly carbon intensive overseas operations in Indonesia (via 50% JV share), nor does one of the key decarbonization technologies (HyREX) appear in the CAPEX plan included in the AR 2023 (Form 20-F).[130]

We modelled the following changes:

- + 2.5 MTPA scrap-EAF at POSCO Gwangyang steel plant currently under construction to come online in 2026 (substituting for 2.5 MTPA BF-BOF capacity)[131]
- Announced +3.0 MTPA BF expansion at KS Posco Cilegon steel plant to come online in 2025 (start date given by GEM).
- +0.3 MT HyREX DRI at POSCO Pohang steel plant by 2027[132]
    - Assumed ramp up to 1 MT in 2030 to reach "commercial scale."[133]
- As no phase-out date for BFs is stated although the "[t]he ultimate goal is to achieve carbon neutrality by gradually converting existing blast furnace facilities to HyREX facilities"[134], we modelled capacity substitution at the end of the economic lifetime of each BF unit at integrated plants in South Korea which are switched to HyREX DRI after 2030. BF units requiring relining before 2030 will be relined based on existing BF technology. . As the company stated the aim to use green hydrogen for the ramp up of HyREX but did not give a start year for H2-DRI-EAF, we assumed that green H2 will be available at commercial scale from 2030 (see *Methods*).

[126] Sustainability Report 2022, see here: https://www.posco.co.kr/homepage/servlet/FileDown?file=/hfiles/enboard/2a2fcf0d18a2b830cc0e861c8173b413.pdf&filename=2022%20POSCO%20Sustainability%20Report.pdf
[127] https://www.posco.co.kr/homepage/docs/eng7/jsp/climate/s91c6000010a.jsp
[128] Sustainability Report 2022, pp. 35 (https://www.posco.co.kr/homepage/servlet/FileDown?file=/hfiles/enboard/2a2fcf0d18a2b830cc0e861c8173b413.pdf&filename=2022%20POSCO%20Sustainability%20Report.pdf)
[129] https://newsroom.posco.com/en/poscos-carbon-neutrality-2050-declaration-background-and-achievement-goals/
[130] AR2023 (Form 20-F), p. 63 (https://www.posco-inc.com:4453/resource/v3/file/investor/2023Form20-F.pdf)
[131] AR2023 (Form 20-F), p. 63 (https://www.posco-inc.com:4453/resource/v3/file/investor/2023Form20-F.pdf)
[132] https://newsroom.posco.com/en/posco-starts-to-design-the-hyrex-demonstration-plant/ ; https://newsroom.posco.com/en/posco-takes-a-significant-step-towards-realizing-the-dream-of-hydrogen-reduction-steelmaking-with-the-inauguration-of-its-development-center/
[133] https://newsroom.posco.com/en/posco-takes-a-significant-step-towards-realizing-the-dream-of-hydrogen-reduction-steelmaking-with-the-inauguration-of-its-development-center/
[134] Sustainability Report 2022, pp. 37 (https://www.posco.co.kr/homepage/servlet/FileDown?file=/hfiles/enboard/2a2fcf0d18a2b830cc0e861c8173b413.pdf&filename=2022%20POSCO%20Sustainability%20Report.pdf)

7 Severstal PAO

Reported capacity

All reported steel plants are covered in our modelling. The capacity estimate for 2021 based on GEM data (12 MTPA) is higher than the reported capacity figure (11.3 MTPA).[135]

Production technology assumptions

Since production route-specific information for its production plants was not disclosed by the company, we assumed that the company operates an integrated (BF-EAF) production process at Severstal Cherepovets steel plant instead of a scrap-EAF based production process. For the integrated (BF-EAF) production process, we applied the EF of the integrated BF-BOF route as no production process specific emissions factor was available. As a result, we may overestimate the direct CO_2 emissions for this production process.

Historic and future UR

For the years 2020-2023, we took the total crude steel production reported by the company divided by the total equity share capacity as calculated based on our GEM model (assigned actual equity shares). For future UR, we took the average of the years 2020-2023 at the production route level and kept it constant until 2050.

We modelled the production capacity changes under the BAU and Stated TP scenarios as follows:

BAU scenario

- No specific changes to the production asset were modeled. 2.2 MTPA BF relined in 2025. All other BF units relined post-2030 after 20 years relining cycle.

Stated TP scenario

- No additional asset-specific upgrades or newly build plants announced in CDP report or corporate disclosure.[136] [137] [138] [139] [140]

[135] Business Presentation, November 2021 (https://severstal.com/upload/iblock/2b5/document75832_.pdf)
[136] https://severstal.com/upload/iblock/7d8/SVS_Climate_report_2021_eng_3.pdf
[137] https://severstal.com/upload/iblock/331/Position-paper_EN_final.pdf
[138] https://severstal.com/upload/iblock/0c2/severstal_eco_memorandum_eng_nosign.pdf
[139] https://severstal.com/upload/iblock/8d1/ajjk4c4r0hlxahve9y9094do3l4tq3sn/SVS_Sustainability_Report_2021_ENG.pdf
[140] https://severstal.com/upload/iblock/2f4/1lvldx8bcticei1ij1tlev0m97gqegyp/Sustainability_report_2022_final.pdf

8 SSAB

Reported capacity

All reported steel plants are covered in our modelling. The company reports a crude steel production capacity figure (8.8 MTPA) almost identical to the aggregated capacity figure we retrieved from GEM (8.9 MTPA). The difference comes from slightly higher capacity figures for the two mini-mill assets in the US (1.25 MTPA versus 1.2 MTPA for each).

Production technology assumptions

No specific production technology related assumptions were made.

Historic and future UR

For the years 2020-2023, we took the total crude steel production reported by the company divided by the total equity share capacity as calculated based on our GEM model (assigned actual equity shares). For future UR, we took the average of the years 2020-2023 and kept it constant across all production assets until 2050.

We modelled the production capacity changes under the BAU and Stated TP scenarios as follows:

BAU scenario

- SSAB Oxelösund steel plant: SSAB Oxelösund steel plant EAF replacement (EAF expansion) of +1.5 MTPA started construction in late 2023 and planned to come online in Q4 2026, when the company announced to substitute currently operating BF capacity by closing down both BF units. [141] However, under BAU we assume that the announced HYBRIT fossil-free steel demonstration plant[142] will not be able to supply the Oxelösund steel plant with sufficient amounts of green hydrogen DRI, which is why we modelled the production capacity from 2026 going forward to be 50% scrap-EAF and 50% BF-EAF. For the integrated (BF-EAF) production process, we applied the EF of the integrated BF-BOF route as no production process specific emissions factor was available.

Stated TP scenario

The stated TP includes proposed technology changes in the form of switching from BF-BOF production to scrap-EAF and green H2 based DRI-EAF production routes.

- SSAB Oxelösund steel plant: SSAB Oxelösund steel plant EAF replacement (EAF expansion) of +1.5 MTPA started construction in late 2023 and planned to come online in

[141] https://www.ssab.com/en/news/2023/06/ssab-invests-in-green-transformation-of-production-in-oxelsund
[142] https://www.hybritdevelopment.se/en/a-fossil-free-development/direct-reduction-hydrogen-demonstrationscale/

Q4 2026, when the company announced to substitute currently operating BF capacity by closing down both BF units. [143]
    - Under Stated TP scenario, we assume that both BF units are phased out and that the HYBRIT fossil-free steel demonstration plant will supply the Oxelösund steel plant with sufficient amounts of hydrogen DRI from 2026[144], which is why we modelled the production capacity of SSAB Oxelösund steel plant going forward from 2026 to be 50% scrap-EAF and 50% H2-DRI-EAF.
- SSAB Luleå steel plant:
    - EAF plant expansion announced but not under construction yet. We assumed capacity substitution (+2.3 MTPA EAF) and phase-out of the currently operating BF unit as announced by the company.[145] We modelled 2.3 MTPA EAF capacity from 2029 going forward, supplied with 50% scarp and 50% sponge iron sourced from the market.[146]
- SSAB Raahe steel plant:
    - We assumed that the company puts plans into place similar to the announced transformation at Luleå steel plant, because this was announced in AR 2023.[147] We assumed capacity substitution (+2.6 MTPA EAF) and phase-out of the currently operating BF unit as announced by the company.[148] We modelled 2.6 MTPA scrap-EAF capacity from 2029 going forward, supplied with 50% scarp and 50% sponge iron sourced from the market. [149]

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[143] https://www.ssab.com/en/news/2023/06/ssab-invests-in-green-transformation-of-production-in-oxelsund
[144] https://www.hybritdevelopment.se/en/a-fossil-free-development/direct-reduction-hydrogen-demonstrationscale/
[145] https://www.ssab.com/en/news/2024/04/ssab-continues-the-transformation-with-a-fossilfree-minimill-in-lule-sweden
[146] SSAB Capital Markets Day 2023 Presentation, p. 120 ff. (https://www.ssab.com/-/media/files/company/investors/capital-market-day-presentations/2023/ssab_cmd_2023_presentation.pdf?m=20230328080333&_gl=1*hu02yl*_up*MQ..*_ga*MTE4MDA5NTU1OC4xNzIwNzc4NjM2*_ga_P73DB0D2PK*MTcyMDc3ODYzNS4xLjAuMTcyMDc3ODYzNS4wLjAuMTU0MzM2NTk2Nw..*_ga_1SF6K3BNKE*MTcyMDc3ODYzNS4xLjAuMTcyMDc3ODYzNS4wLjAuMTUyODcyNzk3Mw..)
[147] "Transformation to fossil-free steel: In 2022, the SSAB Board of Directors made a strategic decision to fundamentally transform the Nordic strip production and accelerate the Group's green transition. The plan is to build electric arc furnaces and cost efficient steel mills, so-called mini-mills, in both Luleå and in Raahe, which can use a mix of sponge iron and recycled steel. In 2023, SSAB's Board of Directors made an investment decision for the conversion of Oxelösund. The construction of the new electric arc furnace started at the end of 2023. The plan is to start fossil-free steelmaking in Oxelösund, based on recycled scrap and sponge iron by the end of 2026." (AR 2023, p. 96, see https://www.ssab.com/-/media/files/company/investors/annual-reports/2023/ssab-annual-report-2023.pdf?m=20240318093306&_gl=1*onm2y1*_up*MQ..*_ga*MjA0NDA0NzAwNC4xNzIwNzc4MTkx*_ga_1SF6K3BNKE*MTcyMDc3ODE5MC4xLjAuMTcyMDc3ODIwMS4wLjAuMjE0MzY2NjMyNA..*_ga_P73DB0D2PK*MTcyMDc3ODE5MC4xLjAuMTcyMDc3ODIwMS4wLjAuNjc5NzA1ODQx)
[148] https://www.ssab.com/en/news/2024/04/ssab-continues-the-transformation-with-a-fossilfree-minimill-in-lule-sweden
[149] SSAB Capital Markets Day 2023 Presentation, p. 120 ff. (https://www.ssab.com/-/media/files/company/investors/capital-market-day-presentations/2023/ssab_cmd_2023_presentation.pdf?m=20230328080333&_gl=1*hu02yl*_up*MQ..*_ga*MTE4MDA5NTU1OC4xNzIwNzc4NjM2*_ga_P73DB0D2PK*MTcyMDc3ODYzNS4xLjAuMTcyMDc3ODYzNS4wLjAuMTU0MzM2NTk2Nw..*_ga_1SF6K3BNKE*MTcyMDc3ODYzNS4xLjAuMTcyMDc3ODYzNS4wLjAuMTUyODcyNzk3Mw..)

9 Tata Steel

Reported capacity

All reported steel plants are covered in our modelling. The company disclosed a total crude steel production capacity figure (35 MTPA) almost identical to the aggregated capacity figure we retrieved from GEM (35.35 MTPA) for 2022.[150] We updated one of the main production assets in India (Tata Steel Jamshedpur steel plant) according to the disclosed capacity figure (11 MTPA) which was higher than the GEM estimate (10 MTPA).

Production technology assumptions

We made the following plant-specific production technology assumptions:

- Tata Steel BSL Dhenkanal plant ("Meramandali" plant) and Tata Steel Long Products steel plant (part of "Tata Steel Gamharia") both include coal-based DRI production processes.
- **Tata Steel BSL Dhenkanal plant ("Meramandali" plant):** We assumed a production route breakdown of 1.8 MTPA coal-based DRI-EAF capacity and 3.8 MTPA BF-BOF capacity at a total plant capacity of 5.6 MTPA.[151] For the DRI-based capacity expansion project ("Tata Steel BSL Dhenkanal plant DRI-EAF expansion"), we assumed a natural gas-based DRI-EAF production route[152], while the other BF-based capacity expansion project ("Tata Steel BSL Dhenkanal plant BF-BOF expansion") is fully based on the BF-BOF production route.
- **Tata Steel Long Products steel plant:** As information disclosed by the company was unavailable, we assumed total capacity (1.0 MTPA) breakdown of 50% BF-BOF (0.5 MTPA) and 50% coal-based DRI-EAF (0.5 MTPA) for reasons of simplification.
- **Tata Sponge Iron Odisha plant (part of "Tata Steel Gamharia"):** As detailed information on the production process was not made unavailable by the company, we assumed the default EF of coal-based DRI-EAF production process although the available company information suggests that the plant produces DRI as a standalone product and does not include a EAF process. That is why we may overestimate the direct CO2 emissions for this plant.

[150] AR2023 (FY 2022-23), p. 8 (https://www.tatasteel.com/media/21241/tata-steel-limited-ir-2024.pdf)

[151] We grouped together the coal-based DRI-EAF, coal-based DRI-Induction Furnace, and coal-based DRI-CONARC production routes; see p. 61 (Appendix), (https://environmentclearance.nic.in/writereaddata/Online/TOR/08_Apr_2016_144914843AB7KF4JBAnnexurePreFeasibilityReport.pdf)

[152] "For the production of hot DRI (HDRI) as feed material for EAF, a COG based Midrex DR plant of capacity 1.6 MTPY has been envisaged for Stage-II of the expansion. Iron ore pellets produced in captive the pellet plant shall be used as feed materials. A mixture of inplant generated coke oven gas (COG) and treated BOF gas shall be used as reducing agent. Thermal reactor system (TRS) shall be employed to convert COG into reducing gas suitable for use in DR plant. The HDRI produced shall be transported to the EAF by hot transport vessels." Environmental Clearance 2016, p. 21 (https://environmentclearance.nic.in/writereaddata/Online/TOR/08_Apr_2016_144914843AB7KF4JBAnnexurePreFeasibilityReport.pdf)

Historic and future UR

For the years 2020-2023, we took the total crude steel production reported by the company divided by the total equity share capacity as calculated based on our GEM model (assigned actual equity shares). For future UR, we took the average of the years 2020-2023 and kept it constant across all production assets until 2050.

We modelled the production capacity changes under the BAU and Stated TP scenarios as follows:

BAU scenario

The company plans significant crude steel production capacity expansion in India. Tata Steel Limited (India operations) announced a plan to double capacity to "~40 MTPA by 2030" [153].

India

- **Tata Steel BSL Dhenkanal plant ("Meramandali" plant):** we assumed +5.65 MTPA BF-BOF which has been announced already in 2016 to come online by 2029, as well as the +1.55 MTPA DRI-EAF which has been announced to come online by 2029.[154] We assumed those plans are still relevant and in line with the company's goal of doubling its capacity in India as the company stated the following in its most recent AR: "We are exploring plans to increase capacity at our Meramandali operations as well." [155]
- **Tata Sponge Iron Odisha plant:** we assumed that both expansions will not go ahead as the company does not provide any information on those expansion plans and GEM also listed them as "cancelled" as of 2024.[156]
- **Tata Steel Kalinganagar steel plant:** we assumed that the capacity expansion of +5 MTPA BF-BOF under construction will come online by 2025 as stated by the company.[157] We assumed another capacity expansion from 8 MTPA to 13 MTPA, i.e., + 5 MTPA BF-BOF, by 2030 (Phase 3 expansion).[158]
- **Neelachal Ispat Nigam steel plant:** we assumed that the capacity expansion of +4.5 MTPA announced by the company[159] will come online by 2029 (Phase 1 expansion[160]).
- **Tata Steel Punjab steel plant:** we assumed +0.75 MTPA scarp-EAF currently under construction will come online in 2026 as stated by the company.[161]

[153] AR 2023 (FY2022-23), p. 258 (https://www.tatasteel.com/media/18370/tata-steel-ir-2022-23.pdf)
[154] https://environmentclearance.nic.in/writereaddata/Online/TOR/08_Apr_2016_144914843AB7KF4JBAnnexurePreFeasibilityReport.pdf
[155] AR 2024 (FY2023-24), p. 29 (https://www.tatasteel.com/media/21241/tata-steel-limited-ir-2024.pdf)
[156] See https://www.gem.wiki/Tata_Sponge_Iron_Odisha_plant#cite_note-autoref_5-15
[157] AR 2023 (FY2022-23), p. 21 (https://www.tatasteel.com/media/18370/tata-steel-ir-2022-23.pdf), see also AR 2024 (FY2023-24), p. 29 (https://www.tatasteel.com/media/21241/tata-steel-limited-ir-2024.pdf)
[158] AR 2024 (FY2023-24), p. 29 (https://www.tatasteel.com/media/21241/tata-steel-limited-ir-2024.pdf)
[159] https://www.tatasteel.com/media/newsroom/press-releases/india/2022/tata-steel-limited-completes-acquisition-of-neelachal-ispat-nigam-limited-through-its-step-down-subsidiary-tata-steel-long-products-limited/
[160] AR 2024 (FY2023-24), p. 29 (https://www.tatasteel.com/media/21241/tata-steel-limited-ir-2024.pdf)
[161] AR 2024 (FY 2023-24), p. 24 (https://www.tatasteel.com/media/21241/tata-steel-limited-ir-2024.pdf)

United Kingdom

- **Tata Steel Port Talbot steel plant:** we assumed closure of BF 4 & 5 units in 2024 due to the reasons stated by the company which cited a combination of operational, economic and financial factors that would make the continuous operation of the BF-BOF production route economically unviable.[162] As stated in an agreement with the UK Government in 2023, we assumed that the company would start constructing a scrap-EAF production route at reduced total plant capacity (+3.2 MTPA) in 2025 and start operations in 2027 as reported by industry news sources,[163] which is also broadly in line with the company's plan to downsize production capacity in Europe while ramping up capacity in India.

Stated TP scenario

The company's stated TP mainly includes plans for its operations in Europe, including the UK's transition to a scrap-EAF route (which was justified entirely based on economic, not climate-related, reasons) and the transition of operations in the Netherlands. The TP also includes a new scrap-EAF plant in Punjab (India), which we also modelled under BAU as it is already under construction. [164] We did not include several general statements by the company in our modelling, including the "evaluating the feasibility of investments in gas-based DRI … until cost-competitive Green Hydrogen becomes available" [165] because the company does not state at the same time a plan to phase-out its BF-BOF production assets, while it actually heavily invests in expanding BF-BOF production in India (see *BAU scenario* above).

- **Tata Steel IJmuiden steel plant:** we assumed that the company implements the announced plan "to replace one of the two blast furnaces with a Direct Reduced Iron (DRI) plant and an EAF before 2030"[166] and "the second one thereafter" [167] . Further, we assumed the DRI would be fed with natural gas when coming online in 2029 as per company statements.[168] We assumed +3.75 MTPA DRI-EAF by 2029 to replace the same capacity of BF-BOF (3.75 MTPA) and phase out BF unit No 7., and another replacement of the remaining 3.75 BF-BOF capacity by +3.75 MTPA DRI-EAF in 2040 while phasing

[162] The company stated also that both BF units were reaching the end of their economic lifetimes: "During both years TSUK's primary steel making assets in Port Talbot produced significantly below their planned outputs due to operational issues with the assets which were near the end of their useful lives." See AR 2024 (FY 2023-24), p. 279; see also pp. 28, 29, 280, F59, F261 (https://www.tatasteel.com/media/21241/tata-steel-limited-ir-2024.pdf)
[163] https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/metals/042524-tata-steel-uk-to-proceed-with-port-talbot-shutdown-move-toward-electric-arc-furnace-production#:~:text=The%20EAF%20will%20have%20a,mt%20crude%20steel%20per%20year.
[164] AR 2024 (FY2023-24), p. 30-31, 114-125 (https://www.tatasteel.com/media/21241/tata-steel-limited-ir-2024.pdf)
[165] AR 2024 (FY2023-24), p. 118 (https://www.tatasteel.com/media/21241/tata-steel-limited-ir-2024.pdf)
[166] AR 2024 (FY2023-24), p. 29 (https://www.tatasteel.com/media/21241/tata-steel-limited-ir-2024.pdf)
[167] AR 2024 (FY2023-24), p. 25 (https://www.tatasteel.com/media/21241/tata-steel-limited-ir-2024.pdf)
[168] "The DRI, set to initially operate on natural gas, will seamlessly transition to hydrogen when it emerges as an accessible and economically feasible energy source." AR 2024 (FY2023-24), p. 25 (https://www.tatasteel.com/media/21241/tata-steel-limited-ir-2024.pdf)

out BF unit No. 6. in 2040.[169] As the company stated the aim to use green hydrogen[170] but did not give a start year for H2-DRI-EAF, we assumed that green H2 will be available from 2030 (see *Methods*).

[169] AR 2024 (FY2023-24), p. 120 (https://www.tatasteel.com/media/21241/tata-steel-limited-ir-2024.pdf)
[170] "The DRI, set to initially operate on natural gas, will seamlessly transition to hydrogen when it emerges as an accessible and economically feasible energy source." AR 2024 (FY2023-24), p. 25 (https://www.tatasteel.com/media/21241/tata-steel-limited-ir-2024.pdf)

10 ThyssenKrupp

Reported capacity

All reported steel plants are covered in our modelling. The company does not disclose its nominal production capacity, neither in aggregate at the company level nor at the production asset level.

Production technology assumptions

The H2 DRI technology is planned to be a natural gas and potentially hydrogen fueled DRI coupled with a BOF unit to produce crude steel.[171] Since specific information on the planned emission intensity (or emission reduction potential relative to the BF-BOF currently in operation) of this H2-DRI-BOF production route was not available, we assumed a default EF of 1.04 and 0.248 tCO2/t crude steel for the natural gas based and H2 based DRI-BOF production route respectively (see Section *Steel Sample – Emission Factors*).

Historic and future UR

For the years 2020-2022, we took the total crude steel production reported by the company divided by the total equity share capacity as calculated based on our GEM model (assigned actual equity shares). For the year 2023, we took the total crude steel production reported by worldsteel[172] divided by the total equity share capacity as calculated based on our GEM model (assigned actual equity shares). For future UR, we took the average of the years 2020-2023 at the production route level and kept it constant until 2050.

We modelled the production capacity changes under the BAU and Stated TP scenarios as follows:

BAU scenario

- +2.3 MT DRI-BOF at Duisburg plant started construction in March 2024[173] and is assumed to come online in late 2026[174], which is why we assumed that full production would commence in 2027 (2.5MT DRI, and 2.3 MT hot metal)[175]. Assumed capacity substitution as one existing BF unit (BF 9) is retired early[176].
    - Natural gas fueled DRI-BOF for 2027 - 2037[177]
    - Green-H2 fueled DRI-BOF from 2037 - 2050.

[171] https://www.thyssenkrupp-steel.com/en/company/sustainability/climate-strategy/climate-strategy.html
[172] https://worldsteel.org/data/world-steel-in-figures-2024/
[173] https://d2zo35mdb530wx.cloudfront.net/_binary/UCPthyssenkruppAG/5e7695ef-6aeb-49f4-b92b-3abe450eb292/240426_thyssenkrupp_Press-Release_Strategic-Partnership-with-EPCG--002-.pdf
[174] https://www.thyssenkrupp.com/de/newsroom/pressemeldungen/pressedetailseite/thyssenkrupp-steel-awards-a-contract-worth-billions-of-euros-to-sms-group-for-a-direct-reduction-plantone-of-the-worlds-largest-industrial-decarbonization-projects-gets-underway-163184
[175] https://www.thyssenkrupp-steel.com/en/company/sustainability/climate-strategy/climate-strategy.html
[176] https://www.vdi-nachrichten.com/technik/werkstoffe/direktreduktion-diese-anlagentechnik-wird-bei-thyssenkrupp-und-co-den-hochofen-abloesen/
[177] https://ec.europa.eu/commission/presscorner/detail/en/IP_23_3928

Stated TP scenario

The company's stated TP includes proposed technology changes in the form of switching from BF-BOF production to (natural gas and later green H2 based) DRI-BOF production route. The stated TP includes the "tkH2Steel" project, which comprises the "construction and installation of a direct reduction plant and two melting units in Duisburg, which will replace an existing blast furnace. Natural gas, initially used for the operation of the new direct reduction plant, will be gradually phased out and, as of 2037, the plant will be operated using only renewable hydrogen."[178] The stated long-term strategy is that at the Duisburg plant "[t]he coal-based blast furnaces will be replaced by hydrogen-powered direct reduction plants."[179] We modelled the following changes:

- **ThyssenKrupp Steel Duisburg steel plant:** +2.3 MT DRI-BOF at Duisburg plant started construction in March 2024[180] and is assumed to come online in late 2026[181], which is why we assumed that full production would commence in 2027 (2.5MT DRI, and 2.3 MT hot metal)[182]. Assumed capacity substitution as one existing BF unit (BF 9) is retired early[183]. As no phase-out date for BFs is stated, we modelled capacity substitution at the end of the economic lifetime of each BF unit which are switched to H2-DRI after 2030. BF units requiring relining before 2030 will be relined based on existing BF technology.
    - Natural gas fueled DRI-BOF for 2027 - 2037[184]
    - Green-H2 fueled DRI-BOF from 2037 - 2050.

- **Hüttenwerke Krupp Mannesmann (HKM) steel plant:** TK holds 50% in HKM, which announced to phase out BF units and replace them with DRI units (similar to TK). As both companies are in M&A talks, construction has not begun yet.[185] We modelled the following changes:
    - Phase out of 1.5 MTPA BF (Unit B), capacity substitution with +1.5 MTPA DRI plant at HKM in 2025[186]
        - Natural gas DRI for 2025 - 2037[187]

[178] https://ec.europa.eu/commission/presscorner/detail/en/IP_23_3928
[179] https://www.thyssenkrupp.com/en/newsroom/press-releases/pressdetailpage/thyssenkrupp-is-accelerating-the-green-transformation--decision-taken-on-the-construction-of-germanys-largest-direct-reduction-plant-for-low-co2-steel-146809
[180] https://d2zo35mdb530wx.cloudfront.net/_binary/UCPthyssenkruppAG/5e7695ef-6aeb-49f4-b92b-3abe450eb292/240426_thyssenkrupp_Press-Release_Strategic-Partnership-with-EPCG--002-.pdf
[181] https://www.thyssenkrupp.com/de/newsroom/pressemeldungen/pressedetailseite/thyssenkrupp-steel-awards-a-contract-worth-billions-of-euros-to-sms-group-for-a-direct-reduction-plantone-of-the-worlds-largest-industrial-decarbonization-projects-gets-underway-163184
[182] https://www.thyssenkrupp-steel.com/en/company/sustainability/climate-strategy/climate-strategy.html
[183] https://www.vdi-nachrichten.com/technik/werkstoffe/direktreduktion-diese-anlagentechnik-wird-bei-thyssenkrupp-und-co-den-hochofen-abloesen/
[184] https://ec.europa.eu/commission/presscorner/detail/en/IP_23_3928
[185] https://www.presseportal.de/pm/55903/5632894
[186] https://www.hkm.de/fileadmin/Nachhaltigkeit/H2KM_15.02.2022_english.pdf ; https://www.hkm.de/fileadmin/004_Umwelt/H2KM_September_2023_english.pdf
[187] https://ec.europa.eu/commission/presscorner/detail/en/IP_23_3928

        - Green-H2 DRI from 2037 - 2050
    - Phase out of 1.5 MTPA BF (Unit A), capacity substitution with +1.5 MTPA DRI plant at HKM in 2045[188]:
        - Green-H2 DRI from 2045

[188] https://www.hkm.de/fileadmin/Nachhaltigkeit/H2KM_15.02.2022_english.pdf ; https://www.hkm.de/fileadmin/004_Umwelt/H2KM_September_2023_english.pdf

Power Sample – Modelling Assumptions for all 10 Sample Companies

1 Électricité de France S.A. (EDF)

Reported capacity

Most of the material power plants disclosed by the company are covered in our modelling. The company disclosed a total electricity production capacity figure on its website (116902 MW) which is slightly larger than the aggregated capacity figure we retrieved from GEM (112806 MW) for 2022[189]. In its CDP, the company reports based on the accounting approach of financial control. We covered 73% of the aggregated fossil fuel-based power generation capacity for 2022 based on data retrieved from GEM (12423 MW) compared to the information stated in the CDP report (17048 MW). We expect that the difference is a result of different accounting approaches and of the fact that GEM applies capacity thresholds to exclude small electricity generation units. However, in the absence of more detailed company disclosure it is not possible to identify with certainty the reason for the difference in capacity figures.

Historic and future UR

EDF group disclosed its consolidated generation capacity (MW) and generation[190] (GWh) by fuel type on its official open-access data platform. For the years 2020-2023, we utilized its historical annual data and calculated the fuel type-specific UR for each year by dividing the reported annual electricity production (by fuel type) by the reported annual electric production capacity (by fuel type). To estimate the UR going forward, we took the average of the four years 2020-2023 and kept it constant across all production assets until 2050.

BAU scenario

The current electricity mix of the company largely relies on nuclear and renewables. In addition, the company is planning to expand its nuclear and renewable capacity with a number of hydropower, solar, and wind electric production assets listed in GEM as announced or under construction. However, at the same time, this company plans fossil fuel capacity expansion through partially owning new overseas coal and gas power plants, including the following:

- **Fuzhou power station (Phase II Unit 3 and Unit 4) in China**: We assumed that these two coal-powered electric production units (1000 MW each) which have been announced will come online by 2029. Since the company only holds a partial ownership stake of 49%

[189] Open data table of EDF group's consolidated generation capacity (https://opendata.edf.fr/explore/dataset/capacites-de-production-consolidees-du-groupe-edf/table/?disjunctive.sector&sort=-tri)
[190] EDF group's open datasets (https://opendata.edf.fr/explore/?disjunctive.theme&disjunctive.publisher&disjunctive.keyword&sort=modified&refine.publisher=EDF+group&refine.theme=Production+Mix)

in the plant, we assumed that the company starts to increase its coal capacity by 980 MW in 2029.

- **Norte Fluminense 2 power station in Brazil:** We assumed that the natural gas capacity expansion of 1713 MW under construction will come online by 2025 as stated in GEM.
- **Seraing power station in Belgium:** Since the company partially owns 68.6% of this 870 MW natural gas power station, we assumed that the natural gas capacity expansion of 596.82 MW under pre-construction will come online by 2025 as stated in GEM.
- **Son My I power station in Vietnam:** Since the company partially owns 37.5% of this 2250 MW liquified natural gas power station, we assumed that the natural gas capacity expansion of 843.75 MW under pre-construction will come online by 2030 as stated in GEM.
- **Surkhandarya power station in Uzbekistan:** Since the company partially owns 15% of this 1600 MW dual-fueled (natural gas/oil) power station, we assumed that the natural gas capacity expansion of 240 MW under construction will come online by 2027 as stated in GEM.
- **Syrdarya power station in Uzbekistan:** Since the company partially owns 33.3% of this 1573 MW natural gas power station, we assumed that the natural gas capacity expansion of 523.81 MW under construction will come online by 2026 as stated in GEM.
- **Vazzio power station (IC2) in France:** Since the company fully owns this 125 MW natural gas power station unit, we assumed that the natural gas capacity expansion of 125 MW under pre-construction will come online by 2026 as stated in GEM.

Stated TP scenario

The company's TP mainly includes investments in renewables and nuclear power as well as a coal phase-out and replacement plan. The TP also includes new fossil fuel power plants, which we also modelled under BAU as they have already been announced or are under construction. We did not include several general statements by the company in our modelling, including "… set itself the target of achieving Net Zero Emission by 2050 … reducing all its emissions (scope 1, 2 and 3) by 2030 and 2050, in line with a +1.5°C warming scenario as assessed by Moody's"[191]. However, we took more specific technology-related commitments into account, which include a commitment to phase out coal and replace with cleaner energy by 2030.

- We further assumed that the company implements the announced plan of "achieving coal-based electricity production phase-out by 2030"[192]. Further, we assumed "replacement of fuel oil in existing thermal installations with less carbon-intensive fuels (liquid biomass

[191] EDF website (Corporate social responsibility, Carbon neutrality and climate) (https://www.edf.fr/backend/collectivites/backend/groupe/backend/collectivites/backend/groupe/backend/collectivites/backend/groupe/backend/collectivites/backend/groupe/en/the-edf-group/taking-action-as-a-responsible-company/corporate-social-responsibility/carbon-neutrality-and-climate)

[192] EDF Decarbonization Strategy at December 2021, p. 2 (https://www.edf.fr/sites/default/files/contrib/groupe-edf/engagements/rapports-et-indicateurs/2021/edfgroup_decarbonation-strategy_2021-12.pdf)

and possibly gas) as part of the multiannual French energy programming (PPE)" and "reaching 60GW of net capacity in renewables (including hydropower) by 2030" [193].

[193] Moody's investor service (15 Feb 2024), p. 5 (https://www.edf.fr/sites/groupe/files/2024-02/edfgroup_moodys_nza-2_20240215_en.pdf)

2 Enel SpA

Reported capacity

Most of the material power plants disclosed by the company are covered in our modelling. The company disclosed two different figures for the total installed electricity production capacity in 2022, including in the operating data report (90123 MW) [194], and in the CDP report (84578 MW) using the accounting approach of financial control. We expect that the reasons for why these two figures are larger than the aggregated capacity figure we retrieved for the company from GEM (62795 MW) are that (1) GEM applies capacity thresholds to exclude small electric generation units, so some small renewable power plants, particularly hydropower, are not included in GEM; (2) the company reports nuclear capacity of 3328 MW which is not included in GEM; (3) our total owned capacity calculation based on GEM uses the equity share approach instead of the financial control approach applied by the company. We covered ~83% of the aggregated fossil fuel-based power generation capacity for 2022 based on data retrieved from GEM (22858 MW) compared to the information reported in the operating data report and in the CDP report (27688 MW). We expect that difference is a result of different accounting approaches and of the fact that GEM applies capacity thresholds to exclude small electric generation units. However, in the absence of more detailed company disclosure it is not possible to identify with certainty the reason for the difference in capacity figures. The fact that our modelling excludes a number of renewable and nuclear assets does not affect our estimation of Scope 1 CO_2 emissions (see *Methods*).

Historic and future UR

Enel Group disclosed its consolidated generation capacity (MW) and generation (GWh) by fuel type in its operating data report[195,196]. For the years 2020-2023, we utilized its historical annual data and calculated the fuel type-specific UR for each year by dividing the reported annual electric production (by fuel type) by the reported annual electric production capacity (by fuel type). To estimate the UR going forward, we took the average of the four years 2020-2023 and kept it constant across all production assets until 2050.

BAU scenario

The company is actively expanding its renewable capacity with a number of solar, and wind electricity production assets which are listed by GEM as being under construction. However, there are also two fully owned natural gas fueled electricity generation units under construction based on the GEM sample, which we included in our BAU modelling:

[194] ENEL Full Year Group Operating Data Report, p. 7 (FY 2022-23) (https://www.enel.com/content/dam/enel-common/press/en/2022-march/Enel%20Quarterly%20Bulletin%20FY%202021%20-%20EN.pdf)
[195] ENEL Full Year Group Operating Data Report, p. 7 (FY 2022-23) (https://www.enel.com/content/dam/enel-common/press/en/2024-march/Enel%20Quarterly%20Bulletin%20FY%202023%20-%20EN.pdf)
[196] ENEL Full Year Group Operating Data Report, p. 3 (FY 2020-21) (https://www.enel.com/content/dam/enel-common/press/en/2022-march/Enel%20Quarterly%20Bulletin%20FY%202021%20-%20EN.pdf)

- **Termini Imerese power station (Unit 1 and Unit 2) in Italy**: We assumed that these two fully owned natural gas-powered electric production units (150 MW each) which have been under construction will come online by 2024 as stated in GEM and that the company starts to increase its natural gas capacity by 300 MW in 2024.

Stated TP scenario

The company's TP mainly includes early phase-out of thermal coal-based power generation and exit from natural gas-based power generation by 2040. The TP also includes new fossil fuel power plants, which we also modelled under BAU as they are already under pre-construction. We did not include several general statements by the company in our modelling, including "We aim to reach zero emissions by 2040: that's much earlier and much more ambitious than the global net zero goal set for 2050."[197]. However, we took more specific technology-related commitments into account, including the commitment to "exit from coal power generation by 2027 & gas power generation by 2040" and to achieve a "… 100% renewable fleet by 2040" [198].

- We assumed that the company implements the announced plan and replaces thermal coal and natural gas capacity with an identical capacity of renewables.

[197] Enel website, net zero (https://www.enel.com/investors/sustainability/strategy-sustainable-progress/net-zero); Zero Emissions Ambition Report, p. 20 (https://www.enel.com/content/dam/enel-com/documenti/investitori/sostenibilita/zero-emissions-ambition-report.pdf)
[198] ESG focus for investors (April 2024), p 7 (https://www.enel.com/content/dam/enel-com/documenti/investitori/informazioni-finanziarie/2024/esg-focus-for-investors_april2024.pdf)

3 KEPCO

Reported capacity

Most of the material power plants disclosed by the company are covered in our modelling. The company disclosed two different figures for the total installed electricity production capacity in 2022, including in the monthly electric power statistics report (82721 MW)[199], and in the CDP report (111760 MW) using the accounting approach of operational control. The aggregated fossil fuel-based power generation capacity for 2022 that we retrieved from GEM (63415 MW) is 13% larger than the disclosed aggregated fossil fuel capacity for 2022 in the CDP report (56108 MW). We expect that the difference is a result of different accounting approaches since the company does only include those power plants in which is holds operational control (which may exclude the JVs in foreign jurisdictions in which KEPCO holds minority stakes), while our approach takes the equity shares of all JVs into account. However, in the absence of more detailed company disclosure it is not possible to identify with certainty the reason for the difference in capacity figures.

Historic and future UR

KEPCO disclosed its installed capacity (MW) and generation[200] (GWh) by fuel type (coal, LNG, oil) in its monthly electric power statistics in December 2022. For the years 2020-2022, we utilized its historical annual data and calculated the fuel type-specific UR for each year by dividing the reported annual electricity production (by fuel type) by the reported annual electric production capacity (by fuel type). Since the company had not disclosed the electric power statistics for FY 2023 by July 2024, we took the average of the previous three years 2020-2022 as the UR data point for the year 2023. To estimate the UR going forward, we took the average of the four years 2020-2023 and kept it constant across all production assets until 2050.

BAU scenario

While the company is expanding its renewable capacity with a few solar, and wind electric production assets listed by GEM as being under construction, there are also several coal and LNG fired electricity generation units that have been announced or are already under construction and which we included under BAU, including:

- **Yangcheng power station (Phase III Unit 9 and Unit 10) in China**: We assumed that these two partially owned thermal coal-based electricity production units (1000 MW each),

[199] KEPCO's Monthly Electric Power Statistics (December 2022), No 189, p. 2 (https://home.kepco.co.kr/kepco/EN/ntcob/list.do?pageIndex=2&boardSeq=0&boardCd=BRD_000242&menuCd=EN030405&parnScrpSeq=0&categoryCdGroup=&searchCondition=title&searchKeyword=)
[200] KEPCO's official website, Investor Relations, IR Information, IR Resources, No 189 (https://home.kepco.co.kr/kepco/EN/ntcob/list.do?pageIndex=2&boardSeq=0&boardCd=BRD_000242&menuCd=EN030405&parnScrpSeq=0&categoryCdGroup=&searchCondition=title&searchKeyword=)

which have been announced, will come online by 2029. Since the company is only one of the ten parent companies of the plant, we assume the company only has a partial ownership share of 10% and starts to increase its coal capacity by 200 MW in 2029.

- **Boryeong power station (CC5 and CC6) in South Korea:** We assumed that these two fully owned LNG-based electricity production units (500 MW each), which have been announced, will come online by 2025 as stated in GEM and the company starts to increase its LNG capacity by 1000 MW in 2025.
- **Egbin power station (B) in Nigeria:** We assumed that this partially owned LNG-based electricity production unit (1800 MW), which has been announced, will come online by 2025 as stated in GEM. Since the company only has an ownership share of 70%, we assumed it starts to increase its LNG capacity by 1260 MW in 2025.
- **Gimpo CHP power station in South Korea:** We assumed that this fully owned LNG-based electricity production unit (225 MW), which has been under construction, will come online by 2026 as stated in GEM and the company starts to increase its LNG capacity by 225 MW in 2026.
- **Gumi Combined Cycle power plant in South Korea:** We assumed that this fully owned LNG-based electricity production unit (501 MW), which has been under construction, will come online by 2026 as stated in GEM and the company starts to increase its LNG capacity by 501 MW in 2026.
- **Hadong power station (Unit 1-6) in South Korea:** We assumed that these six fully owned LNG-based electricity production units (500 MW each), which have been announced, will come online between 2026 and 2031 as stated in GEM and the company starts to increase its LNG capacity by 500 MW in 2026, 500 MW in 2027, 1000 MW in 2028, 500 MW in 2030 and 1000 MW in 2031.
- **Hai Lang power station (1-1) in Vietnam:** We assumed this partially owned LNG-based electricity production unit (1500 MW), which has been announced, will come online by 2030 as stated in GEM. We assume the company, as one of three parent companies, only has an ownership share of 33.3% and starts to increase its LNG capacity by 500 MW in 2030.
- **Hunts Bay power station in Jamaica:** We assumed that this partially owned LNG-powered electric production unit (143 MW) which have been announced will come online by 2027 as stated in GEM. Since the company only has an ownership share of 40%, we assume it starts to increase its LNG capacity by 57.2 MW in 2027.
- **Lobito power station (1-1, 1-2) in Angola:** We assumed that these two partially owned natural gas-based electricity production units (375 MW each), which have been under pre-construction, will come online by 2027 and 2029 respectively as stated in GEM. Since the company only has a partial ownership share of 25%, it starts to increase its natural gas capacity by 93.75 MW in 2027 and 93.75 MW in 2029 respectively.
- **Palua Indah power station (1, 2) in Malaysia:** We assumed that these two partially owned natural gas-based electricity production units (600 MW each), which have been under construction, will come online by 2024 as stated in GEM. Since the company only has a partial ownership share of 25%, it starts to increase its natural gas capacity by 300 MW in 2024.

- **Samchonpo power station (CC3-CC6) in South Korea:** We assumed that these four fully owned LNG-based electricity production units (560 MW for CC3/CC4 and 500 MW for CC5/CC6), which have been announced, will come online by 2026, 2027 and 2028 as stated in GEM, and that the company starts to increase its LNG capacity by 1120 MW in 2026, 560 MW in 2027 and 560 MW in 2028.
- **Shinsejong power station in South Korea:** We assumed that this fully owned LNG-based electricity production unit (630 MW), which have been under construction, will come online by 2024 as stated in GEM and that the company starts to increase its LNG capacity by 630 MW in 2024.
- **Songkhla Chana power station in Thailand:** We assumed that this fully owned LNG-based electricity production unit (1700 MW), which has been announced, will come online by 2029 and that the company starts to increase its LNG capacity by 1700 MW in 2029.
- **Taean power station (1-6) in South Korea:** We assumed that these four fully owned LNG-based electricity production units (500 MW each), which have been announced, will come online by 2025, 2028 and 2029 and 2032 as stated in GEM, and that the company starts to increase its LNG capacity by 1000 MW in 2025, 500 MW in 2028, 500 MW in 2029 and 1000 MW in 2032.
- **Trumbull Energy Center power station and Ukudu power station in United States:** We assumed that these two partially owned natural gas-based electricity production units (950 MW and 180 MW), which have been under construction, will come online by 2026 and 2024 as stated in GEM. Since the company only has a partial ownership of 33% and 40%, respectively, and that the company starts to increase its natural gas capacity by 72 MW in 2024 and 316.67 MW in 2026.
- **Yeongheung power station (1, 2) in South Korea:** We assumed that these two fully owned LNG-based electricity production units (800 MW each), which have been announced, will come online by 2034 as stated in GEM and that the company starts to increase its LNG capacity by 1600 MW in 2034.

Stated TP scenario

The company's TP mainly includes the phase-out of coal power generation by 2034 and the replacement of coal with natural gas. The TP also includes new fossil fuel power plants, which we also modelled under BAU as they are already under pre-construction. We did not include several general statements by the company in our modelling, including the announcement to "reduce emissions by 80 million tons (37.9%) by 2030, relative to 2017 levels (211 million tons)"[201]. However, we took more specific technology-related commitments into account, including the commitment to "accelerate the efforts for coal exit from overseas projects by selling the existing

[201] KEPCO's TCFD Disclosure Framework, Sustainability Report 2021, p. 63 (https://home.kepco.co.kr/kepco/cmmn/documentViewer1.po?fn=BBS_20211213051247347O&rs=/kepco/synap/doc)

coal-fired power plants by 2030"[202], "convert 24 coal-fired plants with 12.7GW capacity to LNG by 2034"[203] and "a complete phase out of coal by 2050" [204].

- We assumed that the company follows through on its plan by replacing the capacity of the 24 coal-fired plants that come up for reinvestment next (ordered by year of required reinvestment from 2024 onwards) with equivalent LNG capacity. All other coal plants are replaced with equivalent renewable energy capacity by 2050.

[202] https://home.kepco.co.kr/kepco/EN/B/htmlView/ENBJHP001_05.do?menuCd=EN020808
[203] Korea Electric Power Corp, p. 1 (https://www.unpri.org/download?ac=13723)
[204] https://www.climateaction100.org/news/kepco-commits-to-carbon-neutrality-and-coal-phase-out-by-2050/

4 NTPC Ltd

Reported capacity

Most of the material power plants disclosed by the company are covered in our modelling. The company disclosed the same total installed electricity production capacity figure for 2022 (72254 MW)[205] in both the annual report and the CDP report using the accounting approach of operational control. The reported capacity is larger than the aggregated capacity figure we retrieved from GEM (62236 MW) for 2022. We covered ~91% of the aggregated fossil fuel-based power generation capacity for 2022 based on data retrieved from GEM (61907 MW) compared to the reported fossil fuel-based capacity (67919 MW). We expect that the difference is a result of different accounting approaches and of the fact that GEM applies capacity thresholds to exclude small electric generation units. However, in the absence of more detailed company disclosure it is not possible to identify with certainty the reason for the difference in capacity figures.

Historic and future UR

NTPC disclosed its annual plant load factor[206,207,208,209] and the installed capacity (MW) and generation (GWh) by fuel type (coal, gas/liquid) in its annual reports[210,211]. For the years 2020-2023, we utilized this historical annual data and calculated the fuel type-specific UR for each year by dividing the reported annual fuel type-specific electricity production by the reported annual fuel type-specific electricity production capacity. To estimate the UR going forward, we took the average of the four years 2020-2023 and kept it constant across all production assets until 2050.

BAU scenario

The company is expanding its renewable capacity with several solar, wind and hydropower electric production units which are under construction. However, there are also over 15 fossil fuel-based power plants that have been announced or are already under construction based on the GEM and which we included under BAU, including:

- **Anpara-E power station (MUNPL) (Unit 1 and Unit 2) in India**: We assumed that these two partially owned thermal coal-based electricity production units (800 MW each) which have been announced will come online by 2029. Since equity share information was not included in GEM and the company is one of ten listed parent companies, we assumed that

[205] NTPC's integrated annual report (FY2022-23), p. 281 (https://ntpc.co.in/investors/annual-reports/2022-23)
[206] NTPC's integrated annual report (FY2020-21), p. 26, 34 (https://ntpc.co.in/sites/default/files/compliances-reports/Annual-Report-2020-21%5B1%5D.pdf)
[207] NTPC's official website (https://ntpc.co.in/media/press-releases/ntpc-delivers-electrifying-performance-fy-2021-22)
[208] NTPC's integrated annual report (FY2022-23), p. 34 (https://ntpc.co.in/investors/annual-reports/2022-23)
[209] NTPC's official website (https://ntpc.co.in/media/press-releases/ntpc-achieves-422-bu-annual-generation-fy-24)
[210] NTPC's integrated annual report (FY2021-22), p. 229 (https://ntpc.co.in/investors/annual-reports/2021-22)
[211] NTPC's integrated annual report (FY2022-23), p. 281 (https://ntpc.co.in/investors/annual-reports/2022-23)

the company holds a partial ownership of 10% and starts to increase its natural gas capacity by 200 MW in 2029.

- **Barh I power station (Unit 3) in India**: We assumed that this fully owned thermal coal-based electricity production unit (660 MW), which has been under construction, will come online by 2024 and that the company starts to increase its coal capacity by 660 MW in 2024.
- **Darlipali power station in India:** We assumed that this fully owned thermal coal-based electricity production unit (800 MW), which has been pre-permitted, will come online by 2029 and that the company starts to increase its coal capacity by 800 MW in 2029.
- **Khurja power station (Unit 1, Unit 2) in India:** We assumed that these two partially owned thermal coal-based electricity production units (660 MW each), which have been under construction, will come online by 2024 as stated in GEM and that the company starts to increase its coal capacity by 983.4 MW in 2024.
- **Lara Integrated Thermal Power project (Unit 3, Unit 4) in India:** We assumed that these two fully owned thermal coal-based electricity production units (800 MW each), which have been permitted, will come online by 2028 as stated in GEM and that the company starts to increase its coal capacity by 1600 MW in 2028.
- **Meja Thermal Power Project (Stage II Unit 3, 4, 5) in India:** We assumed that these three partially owned thermal coal-based electricity production units (800 MW each), which have been pre-permitted, will come online by 2029. Since the company only has a partial ownership of 50%, it starts to increase its coal capacity by 1200 MW in 2029.
- **North Karanpura power station (Unit 2, Unit 3) in India:** We assumed that these two fully owned thermal coal-based electricity production units (660 MW each), which have been under construction, will come online by 2024 as stated in GEM and that the company starts to increase its coal capacity by 1320 MW in 2024.
- **NTPC Seoni power station (Phase 2) in India:** We assumed that this partially owned thermal coal-based electricity production unit (600 MW), which has been permitted, will come online by 2029. Since the company only has an ownership of 50%, it starts to increase its coal capacity by 300 MW in 2029.
- **Obra Thermal Power Station (D Unit 1 and Unit 2) in India:** We assumed that these two partially owned thermal coal-based electricity production units (800 MW each), which have been announced, will come online by 2027 and 2028. Since the company only holds an ownership stake of 50%, it starts to increase its coal capacity by 400 MW in 2027 and 400 MW in 2028.
- **Patratu JSEB power station (Units 11, 12, 13) in India:** We assumed that these three partially owned thermal coal-based electricity production units (800 MW each), which have been under construction, will come online by 2024 and 2025. Since the company only holds an ownership stake of 50%, it starts to increase its coal capacity by 400 MW in 2024 and 800 MW in 2025.
- **Ramagundam power station (Stage IV Unit 9) in India:** We assumed that this fully owned thermal coal-based electricity production unit (800 MW), which has been under construction, will come online by 2024 as stated in GEM and that the company starts to increase its coal capacity by 800 MW in 2024.

- **Rampal power station (Unit 2) in Bangladesh:** We assumed that this partially owned thermal coal-based electricity production unit (660 MW), which has been under construction, will come online by 2023 as stated in GEM and that the company starts to increase its coal capacity by 330 MW in 2023.
- **Singrauli Super Thermal Power Station (Unit 8, Unit 9) in India:** We assumed that these two fully owned thermal coal-based electricity production units (800 MW each), which have been permitted, will come online by 2029 and that the company starts to increase its coal capacity by 1600 MW in 2029.
- **Sipat power station (Unit 6) in India:** We assumed that this fully owned thermal coal-based electricity production unit (800 MW), which has been pre-permitted, will come online by 2029 and that the company starts to increase its coal capacity by 800 MW in 2029.
- **Talcher power station (Stage III Unit 1 and Unit 2) in India:** We assumed that these two fully owned coal-powered electric production units (660 MW each), which have been under construction, will come online by 2026 and 2027 and that the company starts to increase its coal capacity by 660 MW in 2026 and 660 MW in 2027.
- **Hope Town power station in India:** We assumed that this fully owned LNG-based electricity production unit (50 MW), which has been announced, will come online by 2029 and that the company starts to increase its LNG capacity by 50 MW in 2029.

Stated TP scenario

The company's TP mainly includes investments in renewables. The TP also includes new fossil fuel power plants, which we also modelled under BAU as they are already under pre-construction. We did not include several general statements by the company in our modelling, including "… reduce carbon footprint to achieve Net Zero by 2070."[212]. However, we took more specific technology-related commitments into account, including the commitment of "building a renewable generation portfolio of 60 gigawatts (GW) by 2032"[213]. The TP did not include specific fossil fuel phase-out commitments.

- We assumed that the company follows through on its plan by increasing the renewables capacity by 2032 without phasing out fossil fuel-based electricity production.

[212] NTPC's official website, Energy Transition and Policy Research (ET&PR) Department (https://ntpc.co.in/about-us/corporate-functions/et-pr/about-etpr)
[213] NTPC's official website, Renewable Energy (https://ntpc.co.in/power-generation/renewable-energy)

5 Iberdrola S.A.

Reported capacity

Most of the material power plants disclosed by the company are covered in our modelling. The company disclosed two different total installed electricity production capacity figures for 2022, including in the annual report (60760 MW)[214], and the CDP report (53616 MW) using the accounting approach of operational control. These disclosed capacity figures are significantly larger than the aggregated capacity figure we retrieved from GEM (16694 MW) for 2022. Importantly, we covered ~79% of the aggregated fossil fuel-based power generation capacity for 2022 based on data retrieved from GEM (7329 MW) compared to the disclosed fossil fuel-based capacity (9291 MW). We expect that the difference is a result of different accounting approaches and of the fact that GEM applies capacity thresholds to exclude small electric generation units. However, in the absence of more detailed company disclosure it is not possible to identify with certainty the reason for the difference in capacity figures.

Historic and future UR

Iberdrola SA disclosed its owned capacity (MW) and generation (GWh) by fuel type (coal, LNG, oil) in its integrated annual reports[215,216]. In the annual reports, this company states that "data for production and installed capacity include the power stations in which Iberdrola has a stake, based on its percentage interest". For the years 2020-2023, we utilized this historical annual data to calculate the fuel type-specific UR for each year by dividing the reported annual fuel type-specific electricity production by the reported annual fuel type-specific electricity production capacity. To estimate the UR going forward, we took the average of the four years 2020-2023 and kept it constant across all production assets until 2050.

BAU scenario

The company is actively expanding its renewable capacity with several solar, wind, and hydropower plants under construction. There are no new fossil fuel-based electricity production units announced or under construction as per GEM.

Stated TP scenario

The company's TP mainly includes the phase-out of coal power generation by 2034 and the replacement of coal with natural gas. We did not include several general statements by the company in our modelling, including the announcement to "achieve a Net Zero emissions balance

[214] Iberdrola's integrated annual report (FY2022-23), p. 32 (https://www.iberdrola.com/documents/20125/1606413/gsm22_IA_IntegratedReport22.pdf)
[215] Iberdrola's integrated annual report (FY2021-22), p. 28 (https://www.iberdrola.com/documents/20125/1606413/gsm22_IA_IntegratedReport22.pdf)
[216] Iberdrola's integrated annual report (FY2022-23), p. 32 (https://www.iberdrola.com/documents/20125/42388/IB_Integrated_Report.pdf)

by 2040"[217]. However, we took more specific technology-related commitments into account, including the commitment to "achieve emissions neutrality in Scopes 1 and 2 by 2030" with "100% renewables"[218].

- We assumed that the company follows through on its plan by replacing the fossil fuel-based capacity with equivalent capacity of renewables. The company did not disclose retirement years for its fossil fuel-based electricity production units. Since the next reinvestment year for all respective fossil-fule based electricity production units based on our reinvestment cycle modelling are after 2030, we modelled early retirenment of units by randomly selecting a year between 2025-2030 to gradually substitute fossil fuel-based with renewables capacity.

[217] Iberdrola's Greenhouse Gas Report Inventory 2023, p. 3 (https://home.kepco.co.kr/kepco/cmmn/documentViewer1.po?fn=BBS_20211213051247347O&rs=/kepco/synap/doc)
[218] Iberdrola's Climate Action Plan (https://www.iberdrola.com/shareholders-investors/operational-financial-information/annual-reports/integrated-report-esg/)

6 Engie SA

Reported capacity

Most of the material power plants disclosed by the company are covered in our modelling. The company disclosed two different total installed electric production capacity figures, including in the annual report (59900 MW)[219], and in the CDP report 2021 (61424 MW) using the accounting approach of financial control. The reported capacity is larger than the aggregated capacity figure we retrieved from GEM (32136 MW) for 2022. We covered ~90% of the aggregated fossil fuel-based power generation capacity for 2022 based on data retrieved from GEM (24807 MW) compared to the reported fossil fuel-based capacity (27501 MW). We expect that the difference is a result of different accounting approaches and of the fact that GEM applies capacity thresholds to exclude small electric generation units. However, in the absence of more detailed company disclosure it is not possible to identify with certainty the reason for the difference in capacity figures.

Historic and future UR

Engie disclosed its owned capacity (MW) and generation (GWh) by fuel type (coal, natural gas, other non-renewables) in its integrated annual reports for the years 2020-2023[220,221,222,223]. For the years 2020-2023, we utilized this historical annual data to calculate the fuel type-specific UR for each year by dividing the reported annual fuel type-specific electricity production by the reported annual fuel type-specific electricity production capacity. To estimate the UR going forward, we took the average of the four years 2020-2023 and kept it constant across all production assets until 2050.

BAU scenario

The company is actively expanding its renewable capacity with several few solar, and wind electric production assets under construction. However, there are also two partially owned natural gas-based electricity generation units under construction, which we included under BAU, including:

[219] Engie's integrated annual report, p. 12 (https://www.engie.com/sites/default/files/assets/documents/2022-02/ENGIE%20FY%202021%20Databook%20VDEF.pdf)
[220] Engie's integrated annual report (FY2020), p. 6, 12 (https://www.engie.com/sites/default/files/assets/documents/2021-03/ENGIE%20DATABOOK%20FY%202020%20VDEF.pdf)
[221] Engie's integrated annual report (FY2021), p. 12 (https://www.engie.com/sites/default/files/assets/documents/2022-02/ENGIE%20FY%202021%20Databook%20VDEF.pdf)
[222] Engie's integrated annual report (FY2022), p. 12 (https://www.engie.com/sites/default/files/assets/documents/2023-02/ENGIE%20FY%202022%20Databook%20PDF.pdf)
[223] Engie's integrated annual report (FY2023), p. 23 (https://www.engie.com/sites/default/files/assets/documents/2024-02/ENGIE%20FY%202023%20Databook%20VDEF.pdf)

- **Les Awirs power station (CC1) in Belgium**: We assumed that this fully owned natural gas-based electricity production unit (875 MW), which has been under pre-construction, will come online by 2025 as stated in GEM and that the company starts to increase its natural gas capacity by 875 MW in 2025.
- **Mejillones power station (Unit 4) in Chile:** We assumed that this fully owned natural gas-based electricity production unit (375 MW), which has been announced, will come online by 2025 as stated in GEM and that the company starts to increase its natural gas capacity by 375 MW in 2025.

Stated TP scenario

The company's TP mainly includes the phase-out of coal power generation and the replacement of natural gas with biogas and green H2 as well as investments in renewables. The TP also includes new fossil fuel power plants, which we modelled under BAU (stated above) as these are already under pre-construction. We did not include several general statements by the company in our modelling, including the announcement to "achieve the Net Zero Carbon target by 2045". However, we took more specific technology-related commitments into account, including the commitment to "phase out coal by 2025 in Europe and by 2027 globally[224]", "substitute fossil gas with renewable gas (biomethane and hydrogen) once industrial maturity has been reached", "boost offshore wind and solar capacity to 38 GW in 2022, 50 GW in 2025, and 80 GW in 2030, namely 4 GW per year of additional capacity until 2025, and 6 GW per year of additional capacity from 2025 to 2030", and "develop a green hydrogen production capacity of around 4 GW by 2030"[225,226]:

- We assumed that the company follows through on its plan by phasing out coal in Europe by 2025 and globally by 2027 and modelled the replacement of fossil fuel capacity with equivalent renewable capacity.
- We assumed that the company increases 4 GW per year of additional renewable capacity until 2025, and 6 GW per year of additional renewable capacity from 2025 to 2030.
- For the switch from natural-gas based to "renewable gas" based electricity generation, we assumed that Engie would eventually supply all its gas power plants with green H2. We assumed that green H2 will become available at industrial scale from 2030 (see *Methods*). This timeline is further justified by the fact that Engie announced to establish its own green H2 production of 4 GW by 2030. However, since the company did not announce a natural gas phase-out year nor stated asset-specific phase-out plans to switch from natural gas to green H2, we assumed that the company would switch to green H2 at the end of the current reinvestment cycle of each natural gas-based unit. For plants for which the end of the

[224] Engie's official website (https://www.engie.com/en/group/our-vision/commitments-for-the-climate)
[225] Engie's climate report TCFD report 2022, p. 3 (https://www.engie.com/sites/default/files/assets/documents/2022-06/Cahier-Climat-2022-EN.pdf)
[226] Engie's official website, accelerating decarbonization of the energy sector, July 22, 2021 (https://www.engieimpact.com/insights/decarbonization-energy-sector#:~:text=In%20May%202021%2C%20ENGIE%20announced,emissions%20across%20its%20value%20chain.&text=This%20long%2Dterm%20ambition%20is,well%20below%202%C2%B0C.)

current reinvestment cycle is after 2030, we modelled the switch from natural gas to green H2 thereafter. Since the end of the current reinvestment cycle for three plants was before 2030 (for two plants in 2027 and for one plant in 2028), we assumed that the company would make the necessary reinvestments to extent the lifetime of those natural gas-based power plants until 2030, and modelled the switch from natural gas to green H2 for the period after 2030.

7 NextEra Energy Corp

Reported capacity

Most of the material power plants disclosed by the company are covered in our modelling. The company disclosed the same total installed electricity production capacity figure for 2022 (59478 MW) in the annual report[227] and in the CDP report using the equity share accounting approach. The aggregated total capacity figure that we retrieved from GEM for 2022 is slightly lower (57168 MW) than the disclosed figure. The aggregated fossil fuel-based power generation capacity for 2022 that we retrieved from GEM (29825 MW) is 9% larger than the disclosed aggregated fossil fuel capacity for 2022 in the CDP report (27255 MW). In the absence of more detailed company disclosure it is not possible to identify with certainty the reason for the difference in capacity figures.

Historic and future UR

NextEra Energy disclosed its owned capacity (MW) and generation (GWh) by fuel type (coal, natural gas, oil) in its sustainability report for the years 2020-2022[228]. For the years 2020-2022, we utilized this historical annual data to calculate the fuel type-specific UR for each year by dividing the reported annual fuel type-specific electricity production by the reported annual fuel type-specific electricity production capacity. Since the company did not disclose the electric power statistics for FY 2023 by June 2024, we took the average of the previous three years 2020-2022 as value for the UR in 2023. To estimate the UR going forward, we took the average of the four years 2020-2023 and kept it constant across all production assets until 2050.

BAU scenario

The company is expanding its renewable capacity with numerous solar and wind electricity production assets that are currently under construction. Meanwhile, there are no new fossil fuel-based electricity generation units announced or under construction as per GEM data.

Stated TP scenario

The company's TP mainly includes the phase-out of coal power generation by 2034 and the replacement of coal with natural gas. The TP also includes new fossil fuel-based power plants, which we also modelled under BAU as these are already under pre-construction. We did not include several general transition-related statements by the company in our modelling, including the announcement "to be completely carbon emissions-free by no later than 2045."[229]. However,

[227] NextEra Energy's sustainability report 2023 (https://www.investor.nexteraenergy.com/~/media/Files/N/NEE-IR/Sustainability/Sustainability%202023/2023_By_the_Numbers_vF.xlsx)
[228] NextEra Energy's sustainability report 2023 (https://www.investor.nexteraenergy.com/~/media/Files/N/NEE-IR/Sustainability/Sustainability%202023/2023_By_the_Numbers_vF.xlsx)
[229] NextEra Energy's zero carbon blueprint, p. 6 (https://www.nexteraenergy.com/content/dam/nee/us/en/pdf/NextEraEnergyZeroCarbonBlueprint.pdf)

we took more specific technology-related commitments into account, including (1) Remaining ownership interests in coal plants outside of Florida are expected to be retired by no later than 2028[230]; and (2) Achieve a capacity structure of 89% renewables and 11% nuclear in 2045 ("Real Zero"), which we interpreted as a complete fossil fuel phase out by 2045.

- We assumed that the company follows through on its plan by replacing the retired fossil fuel capacity with equivalent renewable capacity and phasing out of all fossil fuel-based electricity generation by 2045.
- We modelled a gradual phase out of thermal coal and natural gas-based power plants. However, since the company did not announce a natural gas phase-out year nor stated asset-specific phase-out plans to substitute natural gas with renewables capacity, we assumed that the company would phase out gas at the end of the current reinvestment cycle of each natural gas-based unit.

[230] NextEra Energy's CDP response 2023, p. 10 (https://www.investor.nexteraenergy.com/~/media/Files/N/NEE-IR/Sustainability/Sustainability%202023/NEE-%20CDP%20Response%202023.pdf)

8 Duke Energy Corp

Reported capacity

Most of the material power plants disclosed by the company are covered in our modelling. The company disclosed two different total installed electric production capacity figures for 2022, including in the annual report (49870 MW)[231] and in the CDP report (61799 MW) using the equity share accounting approach. The aggregated capacity figure we retrieved from GEM for 2022 is in the middle of the two disclosed figures (56285 MW). The aggregated fossil fuel-based power generation capacity for 2022 that we retrieved from GEM (42483 MW) is 16% larger than the disclosed aggregated fossil fuel capacity for 2022 in the CDP report (36681 MW). In the absence of more detailed company disclosure it is not possible to identify with certainty the reason for the difference in capacity figures.

Historic and future UR

Duke Energy disclosed its owned capacity (MW) and generation (GWh) by fuel type (coal, gas & oil) in its integrated annual reports[232,233]. For the years 2020-2023, we utilized this historical annual data to calculate the fuel type-specific UR for each year by dividing the reported annual fuel type-specific electricity production by the reported annual fuel type-specific electricity production capacity. However, the annual reports did not disclose fuel type-specific capacity and generation figures for oil-based generation, which is why we calculated the UR for oil-based generation drawing on CDP data. To estimate the UR going forward, we took the average of the four years 2020-2023 and kept it constant across all production assets until 2050.

BAU scenario

The company is expanding its renewable capacity with several solar electricity production assets under construction. However, there is also one fully owned natural gas electricity generation unit under construction, which we included under BAU:

- **Lincoln Combustion power station (Unit 17) in United States**: We assumed this fully owned natural gas-based electricity production unit (536 MW), which has been under construction, will come online by 2024 as stated in GEM and that the company starts to increase its natural gas capacity by 536 MW in 2024.

[231] Duke Energy's annual report 2023, p. 35 (https://s201.q4cdn.com/583395453/files/doc_financials/2024/ar/2023-annual-report.pdf)
[232] Duke Energy's annual report 2021, p. 35 (https://s201.q4cdn.com/583395453/files/doc_financials/2021/ar/2021-duke-energy-annual-report.pdf)
[233] Duke Energy's annual report 2023, p. 35 (https://s201.q4cdn.com/583395453/files/doc_financials/2024/ar/2023-annual-report.pdf)

Stated TP scenario

The company's TP mainly includes the phase-out of coal power generation by 2034 and the replacement of coal with natural gas. The TP also includes a new fossil fuel power plant, which we also modelled under BAU (see above) as it is already under construction. We did not include several general statements by the company in our modelling, including the announcement to "achieve net-zero carbon emissions by 2050"[234]. Under TP, we modelled the companies' asset base going forwared based on the capacity, generation and emission projections disclosed in its climate report[235].

- We assumed that the company follows through on its plan to phase out coal by 2035 and gradually phase out gas between 2035 and 2050 by assuming capacity substitution with identical capacity of renewables.

[234] Duke Energy's official website, 2019 (https://news.duke-energy.com/releases/duke-energy-aims-to-achieve-net-zero-carbon-emissions-by-2050)
[235] Duke Energy's 2022 climate report, p. 48, 49 (https://www.duke-energy.com/-/media/pdfs/our-company/2022-climate-report.pdf?rev=c99afa612247408fbe3f155c2126454b)

9 Eskom Holdings SOC Ltd

Reported capacity

Most of the material power plants disclosed by the company are covered in our modelling. The company disclosed two different total installed electricity production capacity figures for 2022, including in the annual report (53976 MW)[236] and in the CDP report (52451 MW) based on the accounting approach of operational control. The aggregated capacity figure for 2022 that we retrieved from GEM was slightly lower (50324 MW). The aggregated fossil fuel-based power generation capacity for 2022 that we retrieved from GEM (45552 MW) is 9% larger than the disclosed aggregated fossil fuel capacity for 2022 in the CDP report (41865 MW). We expect that the difference is a result of the use of different accounting approaches. However, in the absence of more detailed company disclosure it is not possible to identify with certainty the reason for the difference in capacity figures.

Historic and future UR

Eskom disclosed its owned capacity (MW) and generation (GWh) by fuel type (coal, gas turbine) in its integrated annual reports for the years 2020-2023[237,238]. For the years 2020-2023, we utilized this historical annual data to calculate the fuel type-specific UR for each year by dividing the reported annual fuel type-specific electricity production by the reported annual fuel type-specific electricity production capacity. However, as neither the annual reports nor the CDP reports disclosed oil-specific capacity and generation figures, we used the global average UR for oil-based electricity generation units from IEA World Energy Outlook 2023 (=19.1%) [239]. To estimate the UR going forward, we took the average of the four years 2020-2023 and kept it constant across all production assets until 2050.

BAU scenario

The company is sexpanding its renewable capacity with a few solar, and wind electric production assets under construction. However, there are also three fully owned coal and gas fired electric generation units under construction which we included under BAU:

- **Kusile power station (Unit 5 and Unit 6) in South Africa**: We assumed that these two fully owned thermal coal-based electricity production units (800 MW each), which have been under construction, will come online by 2024 and 2025 respectively as stated in GEM

[236] Eskom's integrated annual report 2023, p. 13 (https://www.eskom.co.za/wp-content/uploads/2023/10/Eskom_sustainability_report_2023.pdf)
[237] Eskom's integrated annual report 2020, p. 7 (https://www.eskom.co.za/wp-content/uploads/2022/12/2022_integrated_report.pdf)
[238] Eskom's integrated annual report 2023, p. 13 (https://www.eskom.co.za/wp-content/uploads/2023/10/Eskom_integrated_report_2023.pdf)
[239] IEA World Energy Outlook 2023 (https://iea.blob.core.windows.net/assets/86ede39e-4436-42d7-ba2a-edf61467e070/WorldEnergyOutlook2023.pdf)

and that the company starts to increase its coal capacity by 800 MW in 2024 and 800 MW in 2025.

- **Richards Bay (Eskom) power station in South Africa**: We assumed that this fully owned LNG-powered electric production unit (3000 MW), which has been under pre-construction, will come online by 2029 and that the company starts to increase its LNG capacity by 3000 MW in 2029.

Stated TP scenario

The company's TP mainly includes investments in renewables. The TP also includes new fossil fuel power plants, which we also modelled under BAU (see above) as these is already under construction. We did not include several general statements by the company in our modelling, including the announcement to "achieve net-zero carbon emissions by 2050"[240]. As the company did not disclose any asset-, fuel-, or production technology-specific technology changes or phase-out announcements, and emission estimates are the same under BAU and TP scenarios even as the company marginally increases its renewable capacity.

[240] Eskom's just energy transition fact sheet 2021, p. 1, 2 (https://www.eskom.co.za/wp-content/uploads/2021/10/JET_Factsheet13Oct2021.pdf)

10 Southern Co

Reported capacity

Most of the material power plants disclosed by the company are covered in our modelling. The company disclosed two different total installed electricity production capacity figures for 2022, including in the Sustainability Data Table (45667 MW)[241] and in the CDP report[242] (44846 MW) using the equity share accounting approach. The aggregated capacity figure for 2022 that we retrieved from GEM is lower (32766 MW). We covered ~98% of the aggregated fossil fuel-based power generation capacity for 2022 based on data retrieved from GEM (32652 MW) compared to the reported fossil fuel-based capacity (33223 MW). We expect that the difference is a result of different accounting approaches and of the fact that GEM applies capacity thresholds to exclude small electric generation units. However, in the absence of more detailed company disclosure it is not possible to identify with certainty the reason for the difference in capacity figures.

Historic and future UR

The Southern Co disclosed its owned capacity (MW) and generation (GWh) by fuel type (coal, gas, oil) in its Sustainability Data Table for the years 2020-2023[243,244]. For the years 2020-2023, we utilized this historical annual data to calculate the fuel type-specific UR for each year by dividing the reported annual fuel type-specific electricity production by the reported annual fuel type-specific electricity production capacity. To estimate the UR going forward, we took the average of the four years 2020-2023 and kept it constant across all production assets until 2050.

BAU scenario

There are two new natural gas-based electricity generation units under construction as per GEM that we included under BAU:

- **Barry Steam Plant (Unit 4) in United States**: We assumed this fully owned natural gas-based electricity production unit (350 MW), which has been under pre-construction, will come online by 2028 as stated in GEM and that the company starts to increase its natural gas capacity by 350 MW in 2028.

[241] Southern Co's sustainability data table 2023, p. 4 (http://www.southerncompany.com/content/dam/southerncompany/sustainability/pdfs/Southern_Company_Data_Download.pdf)
[242] Southern Co's CDP climate change questionnaire response 2023 (https://www.southerncompany.com/content/dam/southerncompany/sustainability/pdfs/2023-cdp-climate-change-disclosure.pdf)
[243] Southern Company's Sustainability Data Table 2021-2023, p. 4-5 (http://www.southerncompany.com/content/dam/southerncompany/sustainability/pdfs/Southern_Company_Data_Download.pdf)
[244] Southern Company's ESG Data Table 2017-2020, p. 4 (http://www.southerncompany.com/content/dam/southerncompany/pdfs/about/governance/reports/Southern_Company_Data_Download.pdf)

- **Gaston Steam Plant (Unit 5) in United States**: We assumed this partially owned natural gas-based electricity production unit (952 MW), which has been announced, will come online by 2028 as stated in GEM. Since the company only has a partial ownership share of 50%, we assumed that it starts to increase its natural gas capacity by 476 MW in 2028.

Stated TP scenario

The company's TP mainly includes the phase-out of coal-based power generation. The TP also includes new fossil fuel power plants, which we also modelled under BAU (see above) as these are already under pre-construction. We did not include several general statements by the company in our modelling, including the announcement to "meet our goal of net zero greenhouse gas emissions by 2050". However, we took more specific technology-related commitments into account, including the commitment to "reduce the number of coal-fired units by 91% and reduce coal capacity by 87% by the mid-2030s"[245].

- We assumed that the company follows through on its plan by estimating the replacement of the capacity of 91% of the coal-fired units with an equal capacity of renewbales. To do that, we phased out the thermal coal based generating units by the year of the next required reinvestment (i.e., the end of the current reinvestment cycle) starting from 2024 until 91% of thermal coal-based generating capacity was reached.

[245] Southern Co's official website, coal fleet reduction figure, (https://www.southerncompany.com/sustainability/clean-energy/net-zero-transition.html#)

Note on differences between disclosed and estimated direct CO2 emissions

Here we give possible reasons for why our estimated direct CO_2 emissions may differ from the direct CO_2 emissions dislosed by companies (see *Supplementary Table 4*). It is important to stress that in the absence of more detailed and audited company disclosure, it is not possible to identify with certainty the reason(s) for the difference in CO_2 emission values.

We limit our discussion to cases in which our company-level direct CO_2 emission estimates differ significantly (more than +/- 20%) from disclosed Scope 1 CO_2 emissions. This is because we would expect that a diviation of +/-20% could result from inaccurate assumptions for estimating emissions. For power companies, the default fuel type-specific emission factors, heat rates, and the average utilization rates that we applied at the company level may be lower or higher than the actual values for the power sample companies' power generating units. For steel companies, the default technology type-specific emission factors and the average utilization rates that we applied at the company level may be lower than the actual values for steel sample companies' crude steel production assets.

We also discuss the case of KEPCO because the company disclosed highly inconsistent information for its Scope 1 CO_2 emissions from eletrcitiy generation in 2022 (*see below*).

It is important to stress that in the absence of audited, accurately disclosed CO_2 emission figures, the voluntarily disclosed CO_2 emissions via CDP canot be taken as constituting 'ground truth' data as companies may misreport actual emission values.

Steel sample

ArcelorMittal

The company disclosed Scope 1 GHG emissions of 105.0 $MtCO_2eq$ from steel production in 2022 in its Factbook 2022 report[246] and Scope 1 CO_2 emissions of 113.43 $MtCO_2$ from steel production in 2022 in its 2023 CDP report (C-ST7.4)[247]. For 2022, we estimated direct CO_2 emissions of 90.53 $MtCO_2$ from steel production which is 20.2% lower than the value disclosed by the company via CDP for the same year (113.43 $MtCO_2$), and 13.8% lower than he value disclosed by the company in the Fact Book 2022 for the same year.

Despite the inconsistencies between the 2023 CDP Report and the Fact Book 2022, we may have underestimated the disclosed direct CO_2 emissions significantly. Our modelling covers all of the company's significant crude steel production assets and ~119% of the "achievable crude steel capacity 2022" disclosed in the Fact Book 2022[248].

It could be that our modelling led to a potentially significant underestimation of actual direct CO2 emissions from steel production for the following reasons:

1. **Accounting approach:** AM states that it uses the operational control approach that accounts for 100% of CO_2 emissions from power plants it has operational control over, regardless of the actual ownership shares. Hence, if AM has operational control over some operating fossil fuel plants in which it has a partial ownership share, the equity share approach we applied would contribute to significant underestimation of the direct CO_2 emissions accounted for by AM. For instance, if AM held a 20% equity stake in a plant in which it also held operational control (assuming an eqal distribution of voting rights), it would account for 100% of emissions, while the equity share approach that we applied would only account for 20% of the resulting CO_2 emissons.
    a. Based on GEM's ownership share information and our ownership research based on company disclosure, AM holds a 60% equity share in AM/NS India (60%) and presumably holds operational control. If we accounted for 100% CO2 emissions from these production assets in 2022, this would add ~3.8 MtCO2 to our estimated overall Scope 1 CO2 emissions for 2022. Furthermore, the company also holds a 69% equity share in AM South Africa and presumably holds operational control, which means that we may have underestimated the CO2 emissions for the South African assets. However, the company also holds 40% in ArcelorMittal Acciaierie

[246] See ArcelorMittal Fact Book 2022, p. 30 (https://corporate.arcelormittal.com/media/pfwpkrrw/arcelor-mittal-fact-book-2022.pdf)
[247] See ArcelorMittal, Climate Change 2023 Response to CDP, C-ST7.4.
[248] It remains unclear what the term "achievable capacity" refers to. In the absence of more detailed disclosure at the asset level, it is not possible to determine with certainty for which production assets we overestimated production capacity based on GEM data because the company does not report exact capacity figures for all production assets. See ArcelorMittal Fact Book 2022, p. 4, 40-85 (https://corporate.arcelormittal.com/media/pfwpkrrw/arcelor-mittal-fact-book-2022.pdf)

d'Italia Taranto steel plant and 33.40% in AG der Dillinger Hüttenwerke Dillingen steel plant, but presumably does no hold operational control in either of the two production assets. Here our approach would actually overestimate CO2 emissions compared to the disclosed CO2 emissions by AM according to the operational control approach.

2. **Assumptions for estimating emissions:** The default technology type-specific emission factors and the average utilization rates that we applied at the company level may be lower than the actual values for AM's crude steel production assets.
    a. The largest source of uncertainty results from applying a company-wide UR to all steel production assets. This may lead to a significant underestimation of Scope 1 CO2 emissions from steel production in case we applied a lower than actual UR in jurisdictions with a comparably high technology specific EF, and a higher than actual UR in jurisdictions with a comparably low technology specific EF. For instance, we applied a UR of 60.3% to all of AM's BF-BOF production assets. In case a 4 MT BF-BOF production asset in India was operated at a higher UR (e.g., 70%) at an EF of 3.72 tCO2/t crude steel produced, while a 4 MT BF-BOF production asset in the EU was operated at a lower UR (e.g., 50%) at an EF of 1.77 tCO2/t crude steel produced, then the resulting CO2 emissions were significantly higher than if the same UR were applied to both plants. Yet, in the absence of complete disclosure of annual production outputs at the production asset level, it is not possible to identify with certainty if the reason for the difference in CO2 emissions stems from differences in the UR.

China Steel Corp.

The company disclosed Scope 1 GHG emissions of 18.25 $MtCO_2eq$ for 2022 in its Sustainability Report 2022[249] and Scope 1 CO_2 emission of 18.25 $MtCO_2$ resulting from steel production in 2022 in its 2023 CDP report (C-ST7.4)[250]. For 2022, we estimated direct CO_2 emissions of 32.5 $MtCO_2$ from steel production which is 78.1% higher than the value disclosed by the company via CDP for the same year (18.25 $MtCO_2$).

Thus, we may have overestimated the disclosed direct CO_2 emissions significantly. Our modelling covers all of the company's significant crude steel production assets and 111.9% of the reported crude steel capacity disclosed in the Investor Presentation Dec 2023[251].

It could be that our modelling led to a potentially significant underestimation of actual direct CO2 emissions from steel production for the following reasons:

1. **Accounting approach:** CSC states that it uses the operational control approach that accounts for 100% of CO_2 emissions from power plants it has operational control over, regardless of the actual ownership shares. Hence, if CSC holds a partial ownership share in fossil fuel plants over which it does not have operational control, the equity share approach we applied would contribute to significant overestimation of the direct CO_2 emissions accounted for by CSC. For instance, if CSC held a 20% equity stake in a plant in which it did not hold operational control, it would account for 0% of emissions, while the equity share approach that we applied would only account for 20% of the resulting CO_2 emissons.
    a. Based on GEM's ownership share information, CSC holds a 25% equity share in Formosa Ha Tinh Steel plant (Vietnam) over which it presumably does not have operational control. We estimated and accounted for 25% of direct CO_2 emissions from these production assets in 2022 (=3.8 $MtCO_2$). Here our approach would actually overestimate CO_2 emissions compared to the disclosed CO_2 emissions by CSC according to the operational control approach.
    b. CSC disclosed Scope 3 CO_2 emissions of 8.98 $MtCO_2$ resulting from "Investments" which include "equity financing to a subsidiary, DragonSteel Co. (DSC; 100% ownership)", which represents the subsidiary holding one of three major integrated steel plants of the CSC holding company. The company states that it included the subsidiary's Scope 1 and 2 CO_2 emissions as part of its Scope 3 CO_2 emissions in the "Investments" category.[252] CSC disclosed Scope 1 (C-EU7.4) and Scope 3 CO_2 emissions from investments (C6.5) total 27.23 $MtCO_2$. Our estimate of 32.50

[249] CSC did not specify which corporate activities this value includes. See CSC Sustainability Report, p. 6 (https://www.csc.com.tw/csc_e/esg/pdf/hr-2022e.pdf)
[250] See China Steel Corporation, Climate Change 2023 Response to CDP, C-ST7.4.
[251] See CSC Group Joint Conference Presentation December 21, 2023, p. 45 (https://www.csc.com.tw/csc_e/ss/pst/pdf/2023Dec21.pdf)
[252] See China Steel Corporation, Climate Change 2023 Response to CDP, C6.5.

$MtCO_2$ for 2022 is only 19.4% higher. If we would take the direct CO_2 emissions for the company's JV in Vietnam into account, the difference between our estimate and the company's actual CO_2 emissions would be even smaller. Thus, it is highly likely that CSC accounted for most of the CO_2 emissions associated with its 100% ownership stake in its subsidiary DSC as Scope 3 investments rather than Scope 1 CO_2 emissions from steel production.

2. **Assumptions for estimating emissions:** The default technology type-specific emission factors and the average utilization rates that we applied at the company level may be lower than the actual values for CSC's crude steel production assets.
    a. The company may use scrap-EAF based production as part of its integrated steel assets for which we did not account. As the company did not provide enough information on its EAF-based production, we assumed that the company's EAF is part of the integrated steel production process, which we modelled as a BF-EAF production process. For this process, we applied the default EF for BF-BOF based steel production in Taiwan. This may have led us to overestimate Scope 1 CO_2 emissions from steel production.

Severstal PAO

The company disclosed Scope 1 GHG emissions of 24.47 $MtCO_2eq$ for "stationary fuel combustion" and "production processes" in 2022 in its Sustainability Report 2022[253]. We expect that the emissions in those categories mainly result from steel production. The 2023 CDP Report was not publicly available as of October 2024. The company disclosed Scope 1 CO2 emission of 24.29 $MtCO_2$ resulting from steel production for 2021 in its 2022 CDP report (C-ST7.4)[254]. For 2022, we estimated direct CO_2 emissions of 29.85 $MtCO_2$ from steel production which is 22.2% higher than the value disclosed by the company in the Sustainability Report 2022 for the same year (24.47 $MtCO_2$ eq), which however also include greenhouse gases other than CO_2.

Thus, we may have overestimated the disclosed direct CO_2 emissions significantly. Our modelling covers the company's only significant crude steel production asset (Severstal Cherepovets steel plant) and 106.2% of the reported crude steel capacity disclosed in the Sustainability Report 2023[255].

It could be that our modelling led to a potentially significant overestimation of actual direct CO_2 emissions from steel production for the following reasons:

3. **Accounting approach:**
    a. The company accounts for CO_2 emissions from coking coal supply as part of its upstream Scope 3 GHG emissions in the "Purchased goods and services" category. In 2022, at least 1.21 $MtCO_2$ were from purchased coking coal used in the integrated steel mill asset. Total Scope 3 GHG emissions from "Purchased goods and services" in 2022 were 5.89 $MtCO_2$. The company did not specify how much of Scope 3 GHG emissions in this category are from purchased coking coal.[256]
    b. The EF that we chose for our estimation of direct CO2 emissions from the BOF-BF production process accounts for direct CO2 emissions from coke ovens as part of onside coking coal production, which would than be accounted for as a company's Scope 1 emissions (see *Methods*). That is why we may have significantly overestimated direct CO_2 emissions from steel production compared to the values for Scope 1 CO_2 emissions disclosed by Severstal.
4. **Assumptions for estimating emissions:** The default technology type-specific emission factors and the average utilization rates that we applied at the company level may be higher than the actual values for Severstal's crude steel production asset.

[253] Severstal states that this value includes direct Scope 1 emissions from steel production as well as mining activities, which account for . See Severstal Sustainability Report 2022, p. 124 (https://severstal.com/upload/iblock/2f4/1lvldx8bcticei1ij1tlev0m97gqegyp/Sustainability_report_2022_final.pdf)
[254] See Severstal, Climate Change 2022 Response to CDP, C-ST7.4.
[255] It is unclear if the company disclosure refers to capacity figures or actual production output figures. See Severstal Sustainability Report 2023, p. 19 (https://www.csc.com.tw/csc_e/ss/pst/pdf/2023Dec21.pdf)
[256] See Severstal Sustainability Report 2022, p. 124-125, 178-179 (https://severstal.com/upload/iblock/2f4/1lvldx8bcticei1ij1tlev0m97gqegyp/Sustainability_report_2022_final.pdf)

a. The company may use scrap-EAF based production as part of its integrated steel asset for which we did not account. As the company did not provide enough information on its EAF-based production, we assumed that the company's EAF is part of the integrated steel production process, which we modelled as a BF-EAF production process. For this process, we applied the default EF for BF-BOF based steel production in Russia. This may have led us to overestimate Scope 1 CO2 emissions from steel production.
b. The company states that its GHG emission intensity per t crude steel is 2.21 tCO2 for Scope 1,2 and 3 GHG emissions for 2022.[257] We used an default EF for Scope 1 CO2 emissions of 2.79 tCO2/t crude steel from BF-BOF-based production in Russia (see *Supplementary Table 1*), which may be significantly higher than the actual values for Severstal's crude steel production asset. This may have led us to overestimate Scope 1 CO2 emissions from steel production.

[257] See Severstal Sustainability Report 2022, p. 126 (https://severstal.com/upload/iblock/2f4/1lvldx8bcticei1ij1tlev0m97gqegyp/Sustainability_report_2022_final.pdf)

Power sample

Électricité de France S.A. (EDF)

The company disclosed Scope 1 CO_2 emissions of 23.30 $MtCO_2$ from electricity generation by fossil fuel power plants for 2022 in its Carbon Footprint 2022 report[258] and Scope 1 CO_2 emissions of 23.82 $MtCO_2$ from from electricity generation in 2022 in its 2023 CDP report (C-EU7.4)[259]. For the years of 2020-2023, the direct CO_2 emissions we estimated from the electricity production based on GEM are 17.2 $MtCO_2$ on average, which is significanty less than the reported emissions. For 2022, we estimated direct CO_2 emissions of 16.36 $MtCO_2$ representing a 31.3% lower value than the one disclosed by the company via CDP for the same year (25.37 $MtCO_2$). Therefore, we underestimated the disclosed direct CO_2 emissions significantly. However, given that we only covered 72.9% of EDF's fossil fuel based power generating assets in our modelling, we would expect that our emission estimate is significantly lower than the emissions disclosed by the company.

A significant degree of underestimation could be the result of our modelling for the following reasons:

5. **Missing/inaccurate data:** Missing fossil fuel-based power generation assets and/or capacity might result from GEM excluding small coal plants with nominal capacity of below 30 MW and small oil and gas plants with nominal capacity of below 50 MW or below 20 MW in the European Union and the United Kingdom, respectively. EDF may have a number of undisclosed small fossil fuel plants that are not included in GEM. Moreover, the capacity and/or ownership share information provided by GEM might diviate from the actual capacity or ownership shares held by EDF. This could have resulted in underestimating direct CO_2 emissions as a result of an underestimated equity share capacity figure.
6. **Accounting approach:** EDF states that it uses the financial control approach that accounts for 100% of CO_2 emissions from power plants it has financial control over, regardless of the actual ownership shares. Hence, if EDF has financial control over some operating fossil fuel plants in which it has a partial ownership share, the equity share approach we applied would contribute to significant underestimation of the direct CO_2 emissions accounted for by EDF. For instance, if EDF held a 51% stake in a plant (assuming an eqal distribution of voting rights), it would account for 100% of emissions, while the equity share approach that we applied would only account for 51% of the resulting CO_2 emissons.
7. **Assumptions for estimating emissions:** The default fuel type-specific emission factors, heat rates, and the average utilization rates that we applied at the company level may be lower than the actual values for EDF's power generating units.

[258] See Carbon Footprint 2022 Report by EDF Group (https://www.edf.fr/sites/groupe/files/2023-03/edfgroup_bilan-ges_groupe-edf_2022_va.pdf, p. 4)
[259] See EDF, Climate Change 2023 Response to CDP, C-EU7.4

KEPCO

The company disclosed Scope 1 GHG emissions of 162.07 MtCO2eq for 2022 in its 2023 Sustainability Management Report (which may include other business activities than electricity generation)[260] and two different values for its Scope 1 CO_2 emissions from electricity generation for 2022 in its Climate Change 2023 response to CDP, including the values of 144.3 $MtCO_2$ (C-EU8.2d) and 211.3 MtCO2 (C-EU7.4).[261] The direct CO_2 emissions we estimated from electricity production based on GEM data is 241.0 $MtCO_2$ in 2022, which is 67.0% higher than the value of 144.3 $MtCO_2$ (C-EU8.2d) but only 14.1% higher than the value of 211.3 MtCO2 (C-EU7.4) disclosed via the same CDP response.

Therefore, we may have overestimated the disclosed direct CO_2 emissions, potentially to a significant degree if the value of 144.3 $MtCO_2$ was true. Irrespective of which if the two disclosed values were true, we would expect that our emission estimate is higher than the emissions disclosed by the company because we covered 113.0% of the disclosed fossil fuel based power generating assets in our modelling, and because we applied the equity accounting approach to all power generation assets (partially) owned by KEPCO, while the company's CDP 2023 Report is based on the operational control approach and only coveres power generation assets in South Korea[262].

A significant degree of overestimation could be the result of our modelling for the following reasons:

1. **Accounting approach:** KEPCO states that it uses the operational control approach that accounts for 100% of CO_2 emissions from power plants it has operational control over, and 0% of CO_2 emissions from plants over which it does not have operational control (regardless of its actual ownership share). Hence, if KEPCO has a partial ownership of some fossil fuel plants that it does not have operational control over, the equity share approach we applied would contribute to significant overestimation of the direct CO_2 emissions compared to the operational control approach. For instance, if KEPCO held a 51% stake in a plant but did not hold operational control of the plant (which may be held by its JV partner), it would account for 0% of emissions, while the equity share approach that we applied would account for 51% of the resulting CO_2 emissons. Based on GEM's ownership share information and our ownership share estimates (see *Methods*), KEPCO holds minority shares (<50%) in a significant number of overseas power plants in jurisdictions where it is likely that the domestic JV partner holds operational control (e.g., China, Indonesia). The CDP 2023 report only includes Scope 1 CO2 emissions resulting from KEPCO's operations in South Korea.[263] That is why the accounting approach of

[260] See KEPCO's Sustainability Management Report 2023, p. 70 (https://home.kepco.co.kr/kepco/EN/D/C/KEDCPP004.do?boardCd=BRD_000014&menuCd=EN040106)
[261] See Korea Eletric Power Corp, Climate Change 2023 Response to CDP, C-EU7.4 and C-EU8.2d.
[262] See Korea Eletric Power Corp, Climate Change 2023 Response to CDP, C7.2.
[263] See Korea Eletric Power Corp, Climate Change 2023 Response to CDP, C7.2.

operational control is likely to play a significant role in the difference between disclosed and estimated emissions.

2. **Assumptions for estimating emissions:** The default fuel type-specific emission factors, heat rates, and the average utilization rates that we applied at the company level may be higher than the actual values for KEPCO's power generating units.

However, we suspect that the company might misreport its Scope 1 CO_2 emissions from electricity generation under CDP 2023 Climate Change item C-EU8.2d because the company justifies the disclosure of 0 $MtCO_2$ emissions from coal-based power generation by stating that "KEPCO does not own and operate power plants that consume Coal"[264]. Even under the operational control approach and accounting for the fact that the company only discloses Scope 1 CO2 emissions from electricity generation in the jurisdiction of South Korea, this statement is false as the company fully owns (and thus should also have operational control over) several thermal coal-based power generating assets in South Korea.

[264] See Korea Eletric Power Corp, Climate Change 2023 Response to CDP, C-EU8.2d.

Engie SA

The company disclosed Scope 1 GHG emissions of 27.9 MtCO2 eq. resulting from "Energy Production (controlled assets)" for 2022 in its 2023 TCFD report[265]. In its TCFD report, the company did not specify what "Energy Production" are included and did not disclose Scope 1 (direct) CO_2 emissions from electricity generation only for 2022. However, the company disclosed Scope 1 CO_2 emissions from electricity generation of 27.92 $MtCO_2$ for 2022 in its Climate Change 2023 response to CDP (C-EU7.4).[266]

The direct CO_2 emissions we estimated from fossil fuel-based electricity production based on GEM is 56.31 $MtCO_2$ for 2022, which is 101.7% larger than the disclosed Scope 1 CO_2 emissions via CDP (27.92 $MtCO_2$). Since we only cover 90.2% of fossil fuel-based power generation capacity in our modelling (compared to disclosed nominal capacity), this difference is substantial, yet likely the result of combination of the following two factors:

1. **Accounting approach:** Engie states that it uses the financial control approach that accounts for 100% of CO_2 emissions from operations it has financial control over, regardless of its ownership share. Hence, if Engie has a partial ownership stake in fossil fuel plants that it does not have financial control over, the equity share approach we applied would contribute to a significant overestimation of the direct CO2 emissions compared to the financial control approach. For instance, if Engie held a 49% stake in a plant (assuming an eqal distribution of voting rights), it would account for 0% of emissions since it does not hold financial control of the asset, while the equity share approach that we applied would account for 49% of the resulting CO_2 emissons.
    a. Based on GEM's ownership share information and our ownership share estimates (see *Methods*), Engie holds minority shares (<50%) or 50% ownersgip stakes in a significant number of power plants (summing up to an owned capacity of 9037.4 MW in 2022), which is why it is likely that the accounting approach of financial control plays a significant role in the difference between disclosed and estimated emissions.
    b. Engie disclosed Scope 3 CO_2 emissions of 32.1 MtCO2 resulting from "Investments" which include "GHG emissions from power plants consolidated under the equity method [that] are excluded from the scope 1 perimeter of the Group's environmental reporting."[267] Engie's disclosed Scope 1 (C-EU7.4) and Scope 3 CO2 emissions from investments (C6.5) total 60.1 MtCO2. Our estimate of 56.31 $MtCO_2$ for 2022 is 6.2% lower, which is expected since we only cover 90% of fossil fuel-based power generation capacity in our modelling. Thus, it is highly likely that Engie accounted for most of the CO_2 emissions associated with

[265] See Engie Climate Notebook / TCFD report, p. 13, 16 (https://www.engie.com/sites/default/files/assets/documents/2023-05/ENGIE_CAHIER_CLIMAT_2023_EN-1605_0.pdf)
[266] See Engie SA, Climate Change 2023 Response to CDP, C6.5.
[267] See Engie SA, Climate Change 2023 Response to CDP, C-EU7.4.

its minority equity stakes in power plants (see (a) above) as Scope 3 investments rather than Scope 1 CO_2 emissions from electricity generation.

2. **Assumptions for estimating emissions:** The default fuel type-specific emission factors, heat rates, and the average utilization rates that we applied at the company level may be higher than the actual values for Engie's power generating units.

NextEra Energy Corp

The company disclosed its Scope 1 GHG emissions of 41.99 MtCO2eq for 2022 in its Sustainability Report 2023[268], which includes direct GHG emissions from gas infrasrtcture business activities. In the Sustainability Report 2023, The company did not disclose Scope 1 (direct) CO_2 emissions from electricity generation for 2022. However, the company disclosed Scope 1 CO_2 emissions from electricity generation of 41.35 $MtCO_2$ from eletricity generation in 2022 in its Climate Change 2023 response to CDP (C-EU8.2d).[269]

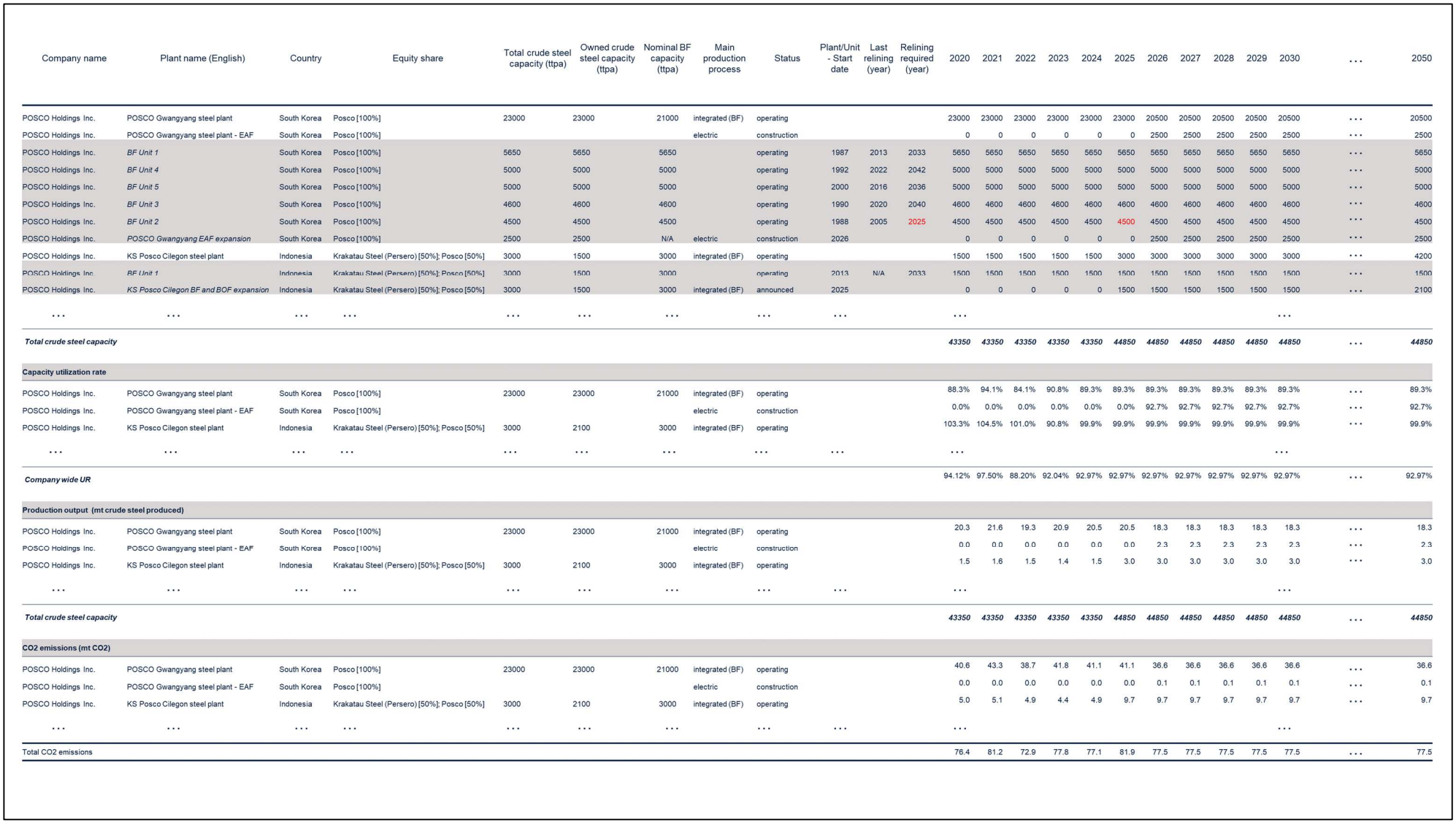
The direct CO_2 emissions we estimated resulting from electricity generation in 2022 based on GEM data are 56.38 $MtCO_2$, which is 36.3% higher than the disclosed CO2 emissions via CDP (41.35 $MtCO_2$). The company used the same accounting approach that we used in our modelling (i.e., equity share approach). We would expect that our emission estimate is higher than the emissions disclosed by the company because we covered 109.4% of the disclosed fossil fuel based power generating assets in our modelling.

The remaining degree of overestimation could be the result of our modelling for the following reasons:

1. **Missing/inaccurate data:** The capacity and/or ownership share information provided by GEM might diviate from the actual capacity or ownership shares held by NextEra Energy Corp. This could have resulted in overestimating direct CO_2 emissions as a result of an inflated equity share capacity figure.
2. **Assumptions for estimating emissions:** The default fuel type-specific emission factors, heat rates, and the average utilization rates that we applied at the company level may be higher than the actual values for NextEra Energy Corp's power generating units.

[268] NextEra Energy's Sustainability Report 2023, Appendix E p. 69 (https://www.nexteraenergy.com/content/dam/nee/us/en/pdf/2023_NEE_Sustainability_Report_Final.pdf)
[269] See NextEra Energy, Climate Change 2023 Response to CDP, C-EU8.2d.

Supplemetary Figures and Tables



Company name	Plant name (English)	Country	Equity share	Total crude steel capacity (ttpa)	Owned crude steel capacity (ttpa)	Nominal BF capacity (ttpa)	Main production process	Status	Plant/Unit - Start date	Last relining (year)	Relining required (year)	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	...	2050
POSCO Holdings Inc.	POSCO Gwangyang steel plant	South Korea	Posco [100%]	23000	23000	21000	integrated (BF)	operating				23000	23000	23000	23000	23000	23000	20500	20500	20500	20500	20500	...	20500
POSCO Holdings Inc.	POSCO Gwangyang steel plant - EAF	South Korea	Posco [100%]				electric	construction				0	0	0	0	0	0	2500	2500	2500	2500	2500	...	2500
POSCO Holdings Inc.	*BF Unit 1*	South Korea	Posco [100%]	5650	5650	5650		operating	1987	2013	2033	5650	5650	5650	5650	5650	5650	5650	5650	5650	5650	5650	...	5650
POSCO Holdings Inc.	*BF Unit 4*	South Korea	Posco [100%]	5000	5000	5000		operating	1992	2022	2042	5000	5000	5000	5000	5000	5000	5000	5000	5000	5000	5000	...	5000
POSCO Holdings Inc.	*BF Unit 5*	South Korea	Posco [100%]	5000	5000	5000		operating	2000	2016	2036	5000	5000	5000	5000	5000	5000	5000	5000	5000	5000	5000	...	5000
POSCO Holdings Inc.	*BF Unit 3*	South Korea	Posco [100%]	4600	4600	4600		operating	1990	2020	2040	4600	4600	4600	4600	4600	4600	4600	4600	4600	4600	4600	...	4600
POSCO Holdings Inc.	*BF Unit 2*	South Korea	Posco [100%]	4500	4500	4500		operating	1988	2005	2025	4500	4500	4500	4500	4500	4500	4500	4500	4500	4500	4500	...	4500
POSCO Holdings Inc.	*POSCO Gwangyang EAF expansion*	South Korea	Posco [100%]	2500	2500	N/A	electric	construction	2026			0	0	0	0	0	0	2500	2500	2500	2500	2500	...	2500
POSCO Holdings Inc.	KS Posco Cilegon steel plant	Indonesia	Krakatau Steel (Persero) [50%]; Posco [50%]	3000	1500	3000	integrated (BF)	operating				1500	1500	1500	1500	1500	3000	3000	3000	3000	3000	3000	...	4200
POSCO Holdings Inc.	*BF Unit 1*	Indonesia	Krakatau Steel (Persero) [50%]; Posco [50%]	3000	1500	3000		operating	2013	N/A	2033	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	...	1500
POSCO Holdings Inc.	*KS Posco Cilegon BF and BOF expansion*	Indonesia	Krakatau Steel (Persero) [50%]; Posco [50%]	3000	1500	3000	integrated (BF)	announced	2025			0	0	0	0	0	1500	1500	1500	1500	1500	1500	...	2100
...	...	...	...	...	...	...		...	...			...										...		
Total crude steel capacity												***43350***	***43350***	***43350***	***43350***	***43350***	***44850***	***44850***	***44850***	***44850***	***44850***	***44850***	...	***44850***
Capacity utilization rate																								
POSCO Holdings Inc.	POSCO Gwangyang steel plant	South Korea	Posco [100%]	23000	23000	21000	integrated (BF)	operating				88.3%	94.1%	84.1%	90.8%	89.3%	89.3%	89.3%	89.3%	89.3%	89.3%	89.3%	...	89.3%
POSCO Holdings Inc.	POSCO Gwangyang steel plant - EAF	South Korea	Posco [100%]				electric	construction				0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	92.7%	92.7%	92.7%	92.7%	92.7%	...	92.7%
POSCO Holdings Inc.	KS Posco Cilegon steel plant	Indonesia	Krakatau Steel (Persero) [50%]; Posco [50%]	3000	2100	3000	integrated (BF)	operating				103.3%	104.5%	101.0%	90.8%	99.9%	99.9%	99.9%	99.9%	99.9%	99.9%	99.9%	...	99.9%
...	...	...	...	...	...	...		...	...			...										...		
Company wide UR												94.12%	97.50%	88.20%	92.04%	92.97%	92.97%	92.97%	92.97%	92.97%	92.97%	92.97%	...	92.97%
Production output (mt crude steel produced)																								
POSCO Holdings Inc.	POSCO Gwangyang steel plant	South Korea	Posco [100%]	23000	23000	21000	integrated (BF)	operating				20.3	21.6	19.3	20.9	20.5	20.5	18.3	18.3	18.3	18.3	18.3	...	18.3
POSCO Holdings Inc.	POSCO Gwangyang steel plant - EAF	South Korea	Posco [100%]				electric	construction				0.0	0.0	0.0	0.0	0.0	0.0	2.3	2.3	2.3	2.3	2.3	...	2.3
POSCO Holdings Inc.	KS Posco Cilegon steel plant	Indonesia	Krakatau Steel (Persero) [50%]; Posco [50%]	3000	2100	3000	integrated (BF)	operating				1.5	1.6	1.5	1.4	1.5	3.0	3.0	3.0	3.0	3.0	3.0	...	3.0
...	...	...	...	...	...	...		...	...			...										...		
Total crude steel capacity												***43350***	***43350***	***43350***	***43350***	***43350***	***44850***	***44850***	***44850***	***44850***	***44850***	***44850***	...	***44850***
CO2 emissions (mt CO2)																								
POSCO Holdings Inc.	POSCO Gwangyang steel plant	South Korea	Posco [100%]	23000	23000	21000	integrated (BF)	operating				40.6	43.3	38.7	41.8	41.1	41.1	36.6	36.6	36.6	36.6	36.6	...	36.6
POSCO Holdings Inc.	POSCO Gwangyang steel plant - EAF	South Korea	Posco [100%]				electric	construction				0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	...	0.1
POSCO Holdings Inc.	KS Posco Cilegon steel plant	Indonesia	Krakatau Steel (Persero) [50%]; Posco [50%]	3000	2100	3000	integrated (BF)	operating				5.0	5.1	4.9	4.4	4.9	9.7	9.7	9.7	9.7	9.7	9.7	...	9.7
...	...	...	...	...	...	...		...	...			...										...		
Total CO2 emissions												76.4	81.2	72.9	77.8	77.1	81.9	77.5	77.5	77.5	77.5	77.5	...	77.5

Supplementary Figure 1 | Simplified illustration of APA for South Korean Steel Maker POSCO under BAU. This figure illustrates the APA applied to South Korean steel maker POSCO based on modelled production capacity, capacity utilization rate, production output, and direct CO2 emission trajectories (top to bottom). Highlighted in grey are sub-plant level production units (e.g., BFs). In red font color is BF unit 3 of POSCO's Gwangyang steel plant which requires relining in 2025 assuming a standard relining cycle of 20 years.

	Direct CO2 Emissions (Scope 1)																				
	Pre-processing				Ironmaking			Steelmaking		Iron- & Steelmaking											
	Coke production	Sintering	Pelletizing for BF-BOF route	Pelletizing for DRI routes	BF	natural gas-based DRI		BOF		Integrated (BF-BOF)			scrap-EAF			natural gas-based DRI-EAF		coal-based DRI-EAF		H2-based DRI-EAF	
Source	IPCC (2019)[6]	IPCC (2019)[6]	IPCC (2019)[6]	Ling et al (2024)[7]	IPCC (2019)[6]	Fan & Friedman (2021)[8]	IPCC (2019)[6]	IPCC (2019)[6]	Orth et al. (2007)[9]	Koolen & Vidovic (2022)[10]	Vogl (2021)[11] / Hasanbeigi & Springer (2019)	IPCC (2019)[6]	Koolen & Vidovic (2022)[10]	IEA (2020)[12]	IPCC (2019)[6]	Shahabuddin et al. (2023)[5] / Sohn (2019)[13]	IEA (2020)[12]	IEA (2020)[12]	Sohn (2019)[13]	Vogl et al. (2018)[4]	Rechberger et al. (2020)[1]
Scope/Boundaries	Coke production using by-product recovery technology (lower end) and without using using by-product recovery technology (higher end)	Sinter production only	Pellet production only	DRI pellet production only	Only BF process included	Only natural gas based DRI production process included	Only natural gas based DRI production process included	Only BOF process included	Only BOF process included	Scope 1, Upstream (trade). Includes coke, sinter and pellet production processes.	Scope unclear. Includes coke, sinter and pellet production processes.	Only BF and BOF processes included. Sinter, coke and pellet production excluded.	Scope 1, Upstream (trade)	Includes direct energy-related and process emissions. Excludes indirect emissions from electricity generation.	Only EAF process	total steel manufacturing using MIDREX shaft furnace integrated with EAF	Includes direct energy-related and process emissions. Excludes indirect emissions from electricity generation.	Includes direct energy-related and process emissions. Excludes indirect emissions from electricity generation.	Direct emissions from rotary kilns	Only DRI-EAF process related emissions included (assumes renewable eletricity supply and excludes DRI pellet production)	DRI process only (assumes renewable eletricity supply and excludes DRI pellet production)
Unit	(tonne of CO2/tonne of coke)	(tonne of CO2/tonne of sinter)	(tonne CO2/tonne pellet produced)	(tCO2 / tDRI)	(tonne CO2/tonne of hot metal)	(tCO2 / tDRI)	(tCO2 / tDRI)	tCO2 / t crude steel	tCO2 / t crude steel	tCO2 / t crude steel		(tonne CO2/tonne of steel produced)	tCO2 / t crude steel	tCO2 / t crude steel	tCO2 /ton of liquid steel	tCO2 / t crude steel	tCO2 / t crude steel	tCO2 / t crude steel		tCO2 / t crude steel	tCO2/t DRI
Country																					
Brazil										2.19	2.02		0.05								
China										1.76	2.33		0.03								
EU										1.77	1.99		0.04		0.18						
India										3.72	2.75		0.07								
Japan										2.05	1.91		0.04								
Russia										2.79	1.83		0.07								
Serbia										2.06			0.06								
South Africa										3.57			0.12								
South Korea										2	2.32		0.03								
Switzerland													0.08								
Taiwan										2.02			0.02								
Turkey										2.17			0.04								
Ukraine										2.3	1.83		0.04								
United Kingdom										2.05			0.04								
United States										1.94	1.82		0.04								
Global	0.51-1.53	0.21	0.19	0.252	1.43	0.52	0.70	0.15	0.25			1.58		0.04		1.10	1.00	~3.0	3.20	0.05	0.04
Mean values						0.61		0.2		2.31			0.05			1.05		3.1			

Supplementary Table 1 | Overview of Selected Emission Factors for Direct CO_2 Emissions from Iron and Steel Production Processes. The EF taken from IPCC (2019) for BOF based steelmaking represents the difference between mean value for EF from BF based iron production and mean value for EF from BF-BOF based steel production (see IPCC 2019, *Table 4.1B*, p. 29)

Company name	BAU/ TP	HQ	Est. Cum. CO2 ('20-'50)	REMIND-MAgPIE				GCAM				MESSAGEix-GLOBIOM			
				NZ 2050		B 2°C		NZ 2050		B 2°C		NZ 2050		2°C	
		Country	(MtCO2)	CB	CO	CB	CO	CB	CO	CB	CO	CB	CO	CB	CO
ArcelorMittal	BAU	LUX	4 122	1 008	309%	1 679	146%	1 410	192%	1 635	152%	3 082	34%	3 251	27%
	Stated TP		3 654		263%		118%		159%		124%		19%		12%
Baoshan Iron & Steel	BAU	CN	2 590	739	250%	1 232	110%	1 035	150%	1 200	116%	2 262	15%	2 386	9%
	Stated TP		2 504		239%		103%		142%		109%		11%		5%
Bluescope Steel	BAU	AUS	279	79	251%	132	111%	111	151%	129	116%	243	15%	256	9%
	Stated TP		279		-		-		-		-		-		-
China Steel	BAU	CN	1 082	292	271%	486	123%	408	165%	473	129%	893	21%	942	15%
	Stated TP		1 082		-	-	-		-		-		-		-
Nippon Steel	BAU	JAP	2 968	622	378%	1 036	187%	870	241%	1 009	194%	1 901	56%	2 006	48%
	Stated TP		2 968		-		-		-		-		-		-
POSCO Holdings	BAU	SK	2 335	664	252%	1 107	111%	930	151%	1 078	117%	2 032	15%	2 143	9%
	Stated TP		1 545		133%		40%		66%		43%		-24%		-28%
Severstal PAO	BAU	RUS	958	279	243%	465	106%	391	145%	453	111%	854	12%	901	6%
	Stated TP		958		-		-		-		-		-		-
SSAB AB	BAU	SWE	279	86	226%	143	96%	120	133%	139	101%	262	7%	277	1%
	Stated TP		92		7%		-36%		-24%		-34%		-65%		-67%
Tata Steel	BAU	IND	3 952	716	452%	1 192	231%	1 002	294%	1 161	240%	2 189	81%	2 309	71%
	Stated TP		3 778		428%		217%		277%		225%		73%		64%
ThyssenKrupp	BAU	GER	528	153	244%	255	107%	215	146%	249	112%	469	13%	494	7%
	Stated TP		345		125%		35%		61%		39%		-26%		-30%
Electricite de France S.A.	BAU	FR	682	75	815%	97	600%	92	644%	124	448%	84	713%	93	636%
	Stated TP		585		685%		501%		538%		370%		598%		532%
Enel SpA	BAU	IT	1 029	129	697%	169	510%	159	548%	215	378%	145	609%	160	541%
	Stated TP		492		281%		192%		210%		129%		239%		207%
Korea Elec. Power Co.	BAU	SK	8 159	1 023	698%	1 336	511%	1 258	549%	1 707	378%	1 150	609%	1 271	542%
	Stated TP		5 955		482%		346%		373%		249%		418%		368%
NTPC	BAU	IND	13 224	1 298	919%	1 695	680%	1 596	729%	2 165	511%	1 459	806%	1 613	720%
	Stated TP		13 224		-		-		-		-		-		-
Iberdrola S.A.	BAU	SP	338	54	523%	71	377%	67	406%	91	273%	61	454%	68	401%
	Stated TP		103		90%		45%		54%		14%		69%		53%
Engie SA	BAU	FR	1 721	237	625%	310	455%	292	489%	396	334%	267	545%	295	483%
	Stated TP		1 299		448%		319%		345%		228%		387%		340%
NextEra Energy	BAU	US	1 753	238	636%	311	464%	293	498%	397	341%	268	555%	296	492%
	Stated TP		1 234		418%		297%		321%		210%		361%		317%
Duke Energy	BAU	US	2 737	410	568%	535	411%	504	443%	684	300%	461	494%	510	437%
	Stated TP		1 539		276%		188%		205%		125%		234%		202%
Eskom Holdings SOC	BAU	SA	7 067	1 037	581%	1 355	422%	1 276	454%	1 731	308%	1 166	506%	1 289	448%
	Stated TP		7 067		-		-		-		-		-		-
The Southern Company	BAU	US	2 862	364	686%	476	501%	5	539%	608	371%	410	599%	453	532%
	Stated TP		2 199		504%		362%		391%		262%		437%		386%

Supplementary Table 2 | Carbon budget (CB) and carbon overshoot (CO) of steel and power companies compared to NGFS scenarios. This table shows the steel and power companies assessed in this study with their respective estimated cumulative emissions (CO_2) for BAU and Stated TP trajectories, and allocated company carbon budgets (both from 2020-2050) as well as relative carbon budget overshoot.

	Req. reinvestment in fossil fuel-based production assets before 2030	Owned capacity fossil fuel-based production assets (equity share)	Owned total production capacity (equity share)	Share of Req. Reinvestment (% of fossil fuel capacity)	Share of Req. Reinvestment (% of total capacity)
Steel sample companies	**Req. Reinvestment Blast Furnace capacity before 2030 (TTPA)**	**Owned Blast Furnace Capacity 2023 (TTPA)**	**Owned Total Crude Steel Capacity 2023 (MW)**	**Share of Req. Reinvestment (% of Blast Furnace Capacity)**	**Share of Req. Reinvestment (% of Total Crude Steel Capacity)**
ArcelorMittal	25334	72697	101652.5	34.8%	24.9%
Baoshan Iron & Steel Co Ltd	27544	46319	52137.2	59.5%	52.8%
Bluescope Steel Ltd	3000	6000	6883	50.0%	43.6%
China Steel Corp.	8616	17025	18055	50.6%	47.7%
Nippon Steel	37836	56187	58877.5	67.3%	64.3%
POSCO Holdings Inc.	14500	42550	43950.5	34.1%	33.0%
SSAB	0	8710	8900	0.0%	0.0%
Severstal PAO	2200	11400	12000	19.3%	18.3%
Tata Steel	3115	23411	36380.7	13.3%	8.6%
ThyssenKrupp AG	2000	14400	16218	13.9%	12.3%
Total Steel sample	124145	298699	355054.4	41.6%	35.0%
Power sample companies	**Req. Reinvestment Fossil Fuel capacity before 2030 (MW)**	**Owned Fossil Fuel Capacity 2023 (MW)**	**Owned Total Power Generating Capacity 2023 (MW)**	**Share of Req. Reinvestment (% Fossil Fuel Capacity)**	**Share of Req. Reinvestment (% Total Power Generating Capacity)**
Électricité de France S.A. (EDF)	2441.18	11328.604	113556.373	21.5%	2.1%
Enel SpA	352.818	17829.147	60844.1042	2.0%	0.6%
Korea Electric Power Corp. (KEPCO)	2744	62809.226	63415.226	4.4%	4.3%
NTPC	10069	60781.7	64708.7	16.6%	15.6%
Iberdrola S.A.	358	7280.3	31848.46667	4.9%	1.1%
Engie SA	467	24807.49689	32152.66689	1.9%	1.5%
NextEra Energy Inc.	1153.474	28233.442	58413.4501	4.1%	2.0%
Duke Energy Corp.	3217.45	41838.6995	56747.0695	7.7%	5.7%
Eskom Holdings SOC Ltd.	14367	45552.1	50324.1	31.5%	28.5%
The Southern Company	2421.087	33287.7865	33401.7865	7.3%	7.2%

Total Power sample	39868.929	333748.5019	565411.9429	11.9%	7.1%

Supplementary Table 3 | Required investments before 2030 in fossil fuel capacity of steel and power companies. The table shows the total owned fossil fuel based as well as total nominal production capacity of steel and power companies which is calculated based on equity share ownership of production assets included in GEM data (see *Methods*).

Company name	Country HQ	Nominal capacity	Production output	Fossil fuel production expansion plans listed in GEM (announced, pre-permit, pre-construction, construction)		GHG emissions consolidation approach (disclosed via CDP)	Reported Scope 1 CO2 emissions (CDP) for 2022 (in mmtCO2)	Reported Scope 1 CO2 emissions (Annual Report or similar) for 2022 (in mmtCO2)	Estimated Scope 1 CO2 emissions for 2022 (in mmtCO2)	% change (Reported compared to estimated value)
Steel company sample		Reported nominal crude steel capacity for 2022 (thousand tons of crude steel)	Reported crude steel production for 2022 (thousand tons of crude steel)	Blast furnace capacity expansion (thousand tons of crude steel)						
ArcelorMittal S.A.	Luxemburg	82,100.0	59,001.0		27,240.00	Operational control	113.43[1]	105.00[2]	90.53	-20.2%
Baoshan Iron & Steel Co Ltd	China	55,000.0	50,964.4		5,340.00	Operational control	91.96[3]	N/A	88.85	-3.4%
Bluescope Steel Ltd	Australien	5,978.0	5,978.0		-	Operational control and equity share	8.31[4]	8.40[5]	8.91	7.2%
China Steel Corp.	China	15,900.0	13,960.0		3,500.00	Operational control	27.23[6]	18.25[7]	32.50	19.4%
Nippon Steel Corp.	Japan	66,000.0	39,130.0		17,360.00	CDP reports not publicly available	N/A	63.40[8]	69.74	10.0%
POSCO Holdings Inc.	South Korea	44,600.0	38,600.0		1,500.00	Operational control	68.30[9]	70.19[10]	71.50	4.7%
Severstal PAO	Russia	11,300.0	10,700.0		-	Operational control	24.29[11]	24.47[12]	29.85	22.0%[13]
SSAB AB	Sweden	8,800.0	7,293.0		-	Operational control	9.84[14]	9.84[15]	9.36	-4.9%
Tata Steel	India	35,000.0	30,650.0		19,970.00	Equity share	74.06[16]	75.50[17]	86.76	17.1%
ThyssenKrupp AG	Germany	Not disclosed	11,000.0		-	Financial control	21.00[18]	21.40[19]	19.21	-8.5%
Power company sample		Reported nominal electricity generation capacity for 2022 (in MW)	Reported electricity generation for 2022 (in GWh)	Coal power capacity expansion (in MW)	Coal, natural gas, and oil power generating capacity expansion (in MW)					
Électricité de France S.A. (EDF)	France	116,902.3	43,419.91	1,713.00	5,022.38	Financial control	23.82[20]	23.30[21]	16.36	-31.3%
Enel SpA	Italy	90,123.0	88,810.00	-	300.00	Financial control	52.49[22]	51.93[23]	42.62	-18.8%
Korea Elec. Power Corp. (KEPCO)	Republic of Korea	82,721.0	360,547.00	200.00	17,791.37	Operational control	211.29[24]	162.07[25]	240.98	14.1%
NTPC	India	72,254.0	371,079.00	16,113.40	16,163.40	Operational control	336.46[26]	304.08[27]	353.18	5.0%
Iberdrola S.A.	Spain	60,760.0	21,305.00	-	-	Operational control	10.71[28]	10.71[29]	10.46	-2.3%
Engie SA	France	58,070.0	105,300.00	-	1,250.00	Financial control	60.05[30]	27.90[31]	56.31	-6.2%
NextEra Energy Inc.	United States	59,478.0	107,382.78	-	-	Equity share	41.35[32]	41.99[33]	56.38	36.3%
Duke Energy Corp.	United States	49,870.0	129,047.93	-	536.00	Equity share	77.00[34]	77.41[35]	89.50	16.2%
Eskom Holdings SOC Ltd.	South Africa	53,976.0	186,394.00	1,600.00	4,600.00	Operational control	197.59[36]	193.16[37]	218.79	10.7%
The Southern Company	United States	45,667.0	141,359.28	-	826.00	Equity share	79.53[38]	84.90[39]	94.72	19.1%

Supplementary Table 4 | Overview of Steel and Power company samples. The table shows the reported nominal production capacity of steel and power companies as well as the fossil fuel-based production capacity expansion plans based on GEM data (see *Methods*). The planned capacity expansion for steel

companies includes blast furnace capacity (announced and under construction), while the expansion capacity for power companies includes thermal coal, natural gas and oil based electricity generation capacity (announced, pre-permit, pre-construction, and construction). Data for Reported Scope 1 CO2 emissions (Annual Report or similar) were taken from annual reports (were available) or from sustainability reports and other official company financial disclosure documents. Since not all companies disclosed Scope 1 CO2 emissions from the core business activities that we modelled (i.e., electricity generation and steel production), we used the next best deisclosed emission value that could serve as proxy for Scope 1 CO2 emissions from the core business activities.

[1] Scope 1 CO_2 emissions from steel production reported for year 2022. See ArcelorMittal 2023 CDP Report, C-ST7.4.
[2] Scope 1 GHG Emissions from steel production reported for year 2022. See ArcelorMittal Fact Book 2022, p. 30. Retrieved from: https://corporate.arcelormittal.com/media/pfwpkrrw/arcelor-mittal-fact-book-2022.pdf
[3] Scope 1 CO_2 emissions from steel production reported for year 2022. See Baosteel 2023 CDP Report, C-ST7.4.
[4] Scope 1 CO_2 emissions from steel production reported for year 2022. See Bluescope 2023 CDP Report, C-ST7.4.
[5] Scope 1 GHG emissions reported for year 2022. See Bluescope Sustainability Data Supplement 2023, p. 13. Retrieved from: https://www.bluescope.com/content/dam/bluescope/corporate/bluescope-com/sustainability/documents/2023_BlueScope_Report_Sustainability_Data_Supplement.pdf
[6] We applied a corrected value which includes Scope 1 CO_2 emissions from steel production reported for year 2022, as well as Scope 3 CO2 emissions of resulting from "Investments"; See CSC 2023 CDP Report, C6.5 and C-ST7.4.
[7] Scope 1 GHG emissions reported for year 2022. See CSC Sustainability Report, p. 6. Retrieved from https://www.csc.com.tw/csc_e/esg/pdf/hr-2022e.pdf
[8] Scope 1 CO2 direct emissions "from owned sources associated with use of fuel" reported for year 2022. See Nippon Steel Integrated Report 2023, p. 72. Retrieved from: https://www.nipponsteel.com/en/ir/library/pdf/nsc_en_ir_2023_a3.pdf
[9] Scope 1 CO_2 emissions from steel production reported for year 2022; see POSCO 2023 CDP Report, C-ST7.4.
[10] POSCO only disclosed a single value for Scope 1 and 2 GHG Emissions from all corporate activities. See POSCO Sustainability Report 2022, p. 42. Retrieved from: https://www.posco.co.kr/homepage/servlet/FileDown?file=/hfiles/board/2a2fcf0d18a2b80bb56e861c8173b413.pdf&filename=2022%20POSCO%20Sustainability%20Report.pdf
[11] Scope 1 CO_2 emissions from steel production reported for year 2021; see Severstal 2022 CDP Report, C-ST7.4.
[12] Scope 1 GHG emissions of 24.47 MtCO2eq for "stationary fuel combustion" and "production processes" reported for year 2022. See Severstal Sustainability Report 2022, p. 178. Retrieved from: https://severstal.com/upload/iblock/2f4/1lvldx8bcticei1ij1tlev0m97gqegyp/Sustainability_report_2022_final.pdf
[13] For Severstal PAO, only the 2022 CDP report was available which included reported Scope 1 CO_2 emissions for the year 2021. That is why we compared the Scope 1 GHG emissions disclosed by the company in its Sustainability Report 2022 (see *Note 12*) to our estimated CO_2 emissions for the year 2022.
[14] Scope 1 CO_2 emissions from steel production reported for year 2022; see SSAB 2023 CDP Report, C-ST7.4.
[15] Scope 1 GHG emissions from production reported for year 2022. See SSAB Annual Report 2023, p. 38. Retrieved from: https://mb.cision.com/Public/980/3947345/8aab378c035efea5.pdf
[16] We included Scope 1 CO2 emissions from all listed business facilities and inter-site adjustments but excluded the mining operation. Reported for year 2022; see 2023 CDP Report, C7.3b.
[17] Scope 1 GHG emissions reported for year 2022. See Tata Steel Annual Report 2022-2023, p. 123. Retrieved from https://www.tatasteel.com/investors/integrated-report-2022-23/index.html
[18] Scope 1 CO_2 emissions for year 2022. See thyssenkrupp 2023 CDP Report, C7.3a.

[19] GHG Scope 1 Emissions for 2021/2022 reporting cycle. See ThyssenKrupp website. Retrieved from: https://www.thyssenkrupp.com/en/investors/esg-information-for-capital-markets
[20] Scope 1 CO2 emissions from electricity generation reported for year 2022. See EDF 2023 CDP Report, C-EU8.2d.
[21]Scope 1 CO2 emissions from electricity generation, reported for year 2022. See EDF CarbonFootprint 2022, p. 4. Retrieved from: https://www.edf.fr/sites/groupe/files/2023-03/edfgroup_bilan-ges_groupe-edf_2022_va.pdf
[22] Scope 1 CO2 emissions from electricity generation reported for year 2022. See Enel 2023 CDP Report, C-EU8.2d.
[23] Scope 1 CO2 emissions from electricity generation reported for year 2022. See Enel Quantification and reporting of greenhouse gas emissions in accordance with the Corporate GHG Protocol (FY22-23), p. 11. Retrieved from: https://www.enel.com/content/dam/enel-com/documenti/investitori/sostenibilita/ghg-inventory-2022.pdf
[24] Scope 1 CO2 emissions from electricity generation reported for year 2022. See Korea Electric Power Corp 2023 CDP Report, C-EU7.4.
[25] Scope 1 GHG emissions, reported for year 2022. See KEPCO's Sustainability Management Report 2023, p. 70. Retrieved from: https://home.kepco.co.kr/kepco/EN/D/C/KEDCPP004.do?boardCd=BRD_000014&menuCd=EN040106
[26] Scope 1 CO2 emissions from electricity generation reported for year 2022. See NTPC 2023 CDP Report, C-EU8.2d.
[27] Scope 1 CO2 emissions from electricity generation and heat reported for year 2022. See NTPC Ltd's Sustainability Data Trends 2023, p. 1. Retrieved from: https://ntpc.co.in/sites/default/files/inline-files/Sustainability%20Data%20Trends%202023_0.pdf
[28] Scope 1 CO2 emissions from electricity generation reported for year 2022. See Iberdrola 2023 CDP Report, C-EU8.2d.
[29] Scope 1 CO2 emissions from electricity generation reported for year 2022. Seee Iberdrola's Greenhouse Gas Report FY2022, p. 16. Retrieved from: https://www.iberdrola.com/documents/20125/41101/GEI_Report_2022.pdf
[30] We applied a corrected value which includes Scope 1 CO_2 emissions from electricity generation reported for year 2022, as well as Scope 3 CO2 emissions of resulting from "Investments". See ee Engie SA 2023 CDP Report, C6.5 and C-EU7.4.
[31] Scope 1 GHG emissions from electricity generation reported for year 2022. See Engie's Climate Notebook / TCFD Report, p. 13, 16. Retrieved from: https://www.engie.com/sites/default/files/assets/documents/2023-05/ENGIE_CAHIER_CLIMAT_2023_EN-1605_0.pdf
[32] Scope 1 CO2 emissions from electricity generation reported for year 2022. See NextEra Energy 2023 CDP Report, C-EU8.2d
[33] Scope 1 GHG emissions reported for year 2022. See NextEra Energy's Sustainability Report 2022, Appendix E, p. 69. Retrieved from: https://www.nexteraenergy.com/content/dam/nee/us/en/pdf/2023_NEE_Sustainability_Report_Final.pdf
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[38] Scope 1 CO2 emissions from electricity generation reported for year 2022. See The Southern Company 2023 CDP Report, C-EU8.2d.
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