Tor Eivind Tjalvin Alvsåker

Manipulating Multi-Regional Input-Output Tables to Evaluate India's COP26 Pledges

Master's thesis in Energy and Environmental Engineering
Supervisor: Juudit Ottelin
June 2023

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Abstract

India is the third largest emitter of greenhouse gases globally. Due to the enormous population and expected huge economic growth, the country has a unique position in influencing future global emissions. During the 2021 United Nations Climate Change Conference, the Indian prime minister presented five pledges concerning India's commitment to climate ambition. The aim of this thesis is to evaluate three of the objectives pledged to be fulfilled by 2030. This is done through manipulated EXIOBASE Multi-Regional Input-Output tables being combined with various power sector and carbon efficiency scenarios. Due to the renewable electricity generation share being deemed likely to be in the range of 30% to 40%, pledge 2 (50% of electricity requirements from renewable sources) is considered highly unlikely to be fulfilled. Pledge 1 (500 GW of non-fossil fuel electricity capacity) is deemed possible to fulfill. Assuming that all other sectors develop according to their historical trends, the fulfillment of pledge 1 is estimated to contribute towards reaching an emission multiplier (i.e., the carbon intensity of an economy's output) decrease of approximately 40% compared to 2005 levels. However, emission savings from carbon efficiency measures are likely to be substantial enough for pledge 4 (45% decrease in emission multiplier compared to 2005 levels) to be fulfilled. The analysis emphasizes significantly increased investments in solar and wind power as key in fulfilling all three pledges. In order to further decrease the emission multiplier, the Indian government should also focus on decelerating the growth in domestic demand of fossil fuels, increasing investments in service sectors, reducing transmission and distribution losses, renovating the coal-fired power sector, and further develop the Perform, Achieve, Trade scheme.

Sammendrag

India har verdens tredje største drivhusgassutslipp. Grunnet deres enorme populasjon og stor forventet økonomisk vekst vil landet ha en unik påvirkning på fremtidige globale utslipp. Under de forente nasjoners klimatoppmøte i 2021 la Indias statsminister frem fem løfter angående Indias klimaambisjoner. Målet med denne masteroppgaven er å evaluere tre av løftene som er lovet å bli innfridd i løpet av 2030. Dette blir gjort ved at manipulerte EXIOBASE Multi-Regional Input-Output tabeller blir kombinert med diverse elektrisitetssektor- og karboneffektiviserings-scenarioer. Grunnet en fornybar elektrisitetsproduksjons-andel som blir ansett som sannsynlig å være mellom 30% og 40%, er løfte 2 (50% av elektrisitetsproduksjon fra fornybare kilder) ansett som meget usannsynlig å bli innfridd. Løfte 1 (500 GW ikke-fossil elektrisitetskapasitet) er ansett som mulig å innfri. Dersom alle andre sektorer utvikler seg i henhold til deres historiske trender, er løfte 1 estimert til å bidra mot å oppnå en nedgang i utslippsmultiplikator (karbonintensiteten til en økonomi) på omtrent 40% sammenlignet med 2005-nivå. Utslippsbesparelsene fra karboneffektiviseringstiltak er derimot ansett som sannsynlig å være store nok til at løfte 4 (45% nedgang i utslippsmultiplikator sammenlignet med 2005-nivå) blir innfridd. Analysen understreker at betydelig økte investeringer i sol- og vind-kraft vil være avgjørende for oppnåelsen av alle de tre løftene. For å ytterligere redusere utslippsmultiplikatoren bør de indiske myndighetene fokusere på å bremse veksten i den nasjonale etterspørselen av fossilt brensel, øke investeringene i servicesektorer, minske overføring- og distribusjons-tap, renovere kullkraftsektoren og videreutvikle Perform, Achieve, Trade-ordningen.

Acknowledgements

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Lastly, I would like to thank my family. I am forever grateful for your support throughout my five years at NTNU.

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Tor Eivind Tjalvin Alvsåker

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List of Abbreviations

\$US15	Constant 2015 US dollar
BAU	Business-as-Usual
CBA	Consumption-based accounting
CCS	Carbon Capture and Storage
CEA	Central Electricity Authority
CH_4	Methane
CO_2	Carbon dioxide
CO_2e	CO_2-equivalent
COP26	The 2021 United Nations Climate Change Conference
CSP	Concentrating solar power
D&L method	Dietzenbacher & Los method
F-gases	Fluorinated gases
GDP	Gross Domestic Product
GFCF	Gross Fixed Capital Formation
GHG	Greenhouse Gas
Gt	Gigatonne
GW	Gigawatt
HDI	Human Development Index
IEA	The International Energy Agency
IEEFA	The Institute for Energy Economics and Financial Analysis
IMF	The International Monetary Fund
kWh	Kilowatt-hour
LED	Light-emitting Diode
LULUCF	Land Use, Land-Use Change & Forestry
MRIO	Multi-Regional Input-Output
Mt	Megatonne
N_2O	Nitrous oxide
NDC	Nationally Determined Contribution
PAT scheme	Perform, Achieve, Trade scheme
PBA	Production-based accounting
PG	Power sector Goals
RoW	Rest of World
SDA	Structural Decomposition Analysis
Solar PV	Solar photovoltaic

TJ	Terajoule
TWh	Terawatt-hour
VRE	Variable Renewable Energy
WIOD	World Input-Output Database

1 Introduction & background

Despite increasing attention about the impacts of climate change, global greenhouse gas (GHG) emissions are still rising[1]. Figure 1 shows the largest emitters of GHGs (excluding Land Use, Land-Use Change & Forestry (LULUCF)) the last decades. Most of them have stabilized or even decreased their emissions. As an example, using 1995 as a base year, the EU27 had decreased their emissions by 20% by 2019. In the other end of the scale China's remarkable development (+195%) stands out. However, in relative terms, India (+135%) is a close second. The 1.44 gigatonnes (Gt) CO_2-equivalents (CO_2e) emitted in 1995 made up 4.5% of global emissions, while the share increased to 7.0% in 2019 due to total emissions of 3.39 Gt CO_2e[1]. India's per capita emissions of 2.46 tonnes were still only equivalent to 38% of the global average[1], which highlights the potential magnitude of the country's future total emissions. Hence, countering the growth in India's emissions with carbon efficiency measures will be key in offsetting further increase in global emissions.

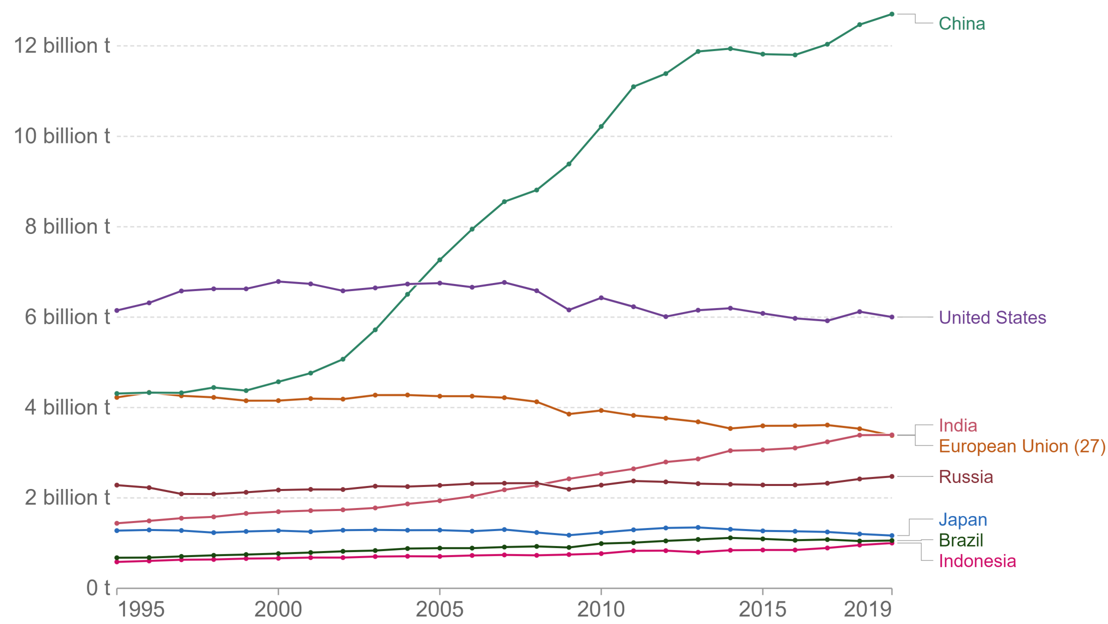


Figure 1: Production-based GHG emissions excluding LULUCF by country [CO_2e][1]

India's increasing emission numbers must be seen in context of the country's economic development. Figure 2 shows India's historical inflation-adjusted Gross Domestic Product (GDP) presented in constant 2015 US$ ($US15). Using 1995 as a base year, the 352% increase in real GDP is more than three times the growth rate of the global average[2]. The data from Figure 1 and Figure 2 can be used to calculate the development in India's emission multiplier. The multiplier is a measure of the carbon intensity of an economy's total output. Figure 3 shows that India's emission multiplier (in kg CO_2e per $US15) decreased from 2.42 in 1995 to 1.77 in 2005, 1.46 in 2015, and 1.26 in 2019. In comparison, the average global

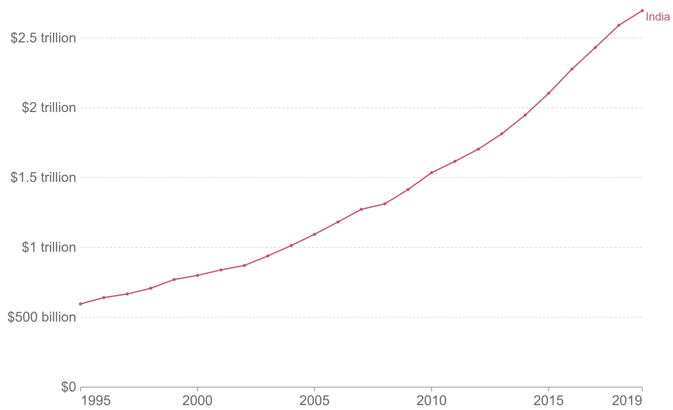


Figure 2: Inflation-adjusted GDP [$US15][2]

emission multiplier was 0.59 kg CO_2e per $US15 in 2019[1] [2]. Thus, despite significant improvements in the last decades, India's economy can be considered quite carbon-intensive, which in part can be explained by the country's extensive use of fossil fuels[3]. This was addressed by prime minister Narendra Modi during the 2021 United Nations Climate Change Conference (COP26), in which he presented five pledges concerning India's commitment to climate ambition. The pledges, presented in Figure 4, have been criticized for being ambiguous and unclear[3]. The first two pledges (marked in green) refer to the energy sector as a whole but are by external sources interpreted to regard the electricity sector[3] [4]. The three remaining pledges (marked in blue) directly focus on reducing emission levels. However, pledge 3 is vague as there is no official projection of India's future emissions[3]. Hence, it is difficult to model. The same goes for pledge 5 concerning net zero emissions by 2070 as it so far into the future. Pledge 4 is thus the pledge handling emissions directly that is the easiest to model as it refers to emissions per GDP (i.e., the emission multiplier of India's economy). According to Figure 3, the emission multiplier in 2030 would have to be 0.97 kg CO_2e per $US15 in order for the objective to be achieved. India officially submitted pledge 4 as part of its updated Nationally Determined Contribution (NDC) in August 2022[4]. A target of increasing the share of non-fossil power capacity to 50% by 2030 was also submitted. This can to a large degree be considered a less ambitious version of pledge 1, as India is not expected to surpass a total of 1000 gigawatt (GW) installed power capacity by 2030[5]. Hence, this NDC will not be the focus of this study.

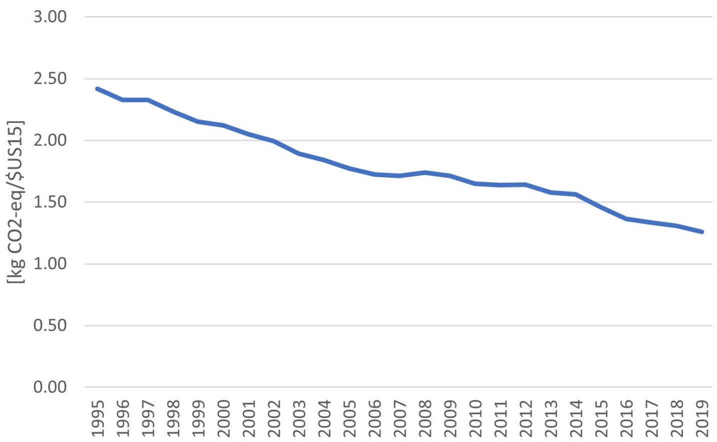


Figure 3: Emission multiplier [kg CO_2e per $US15]

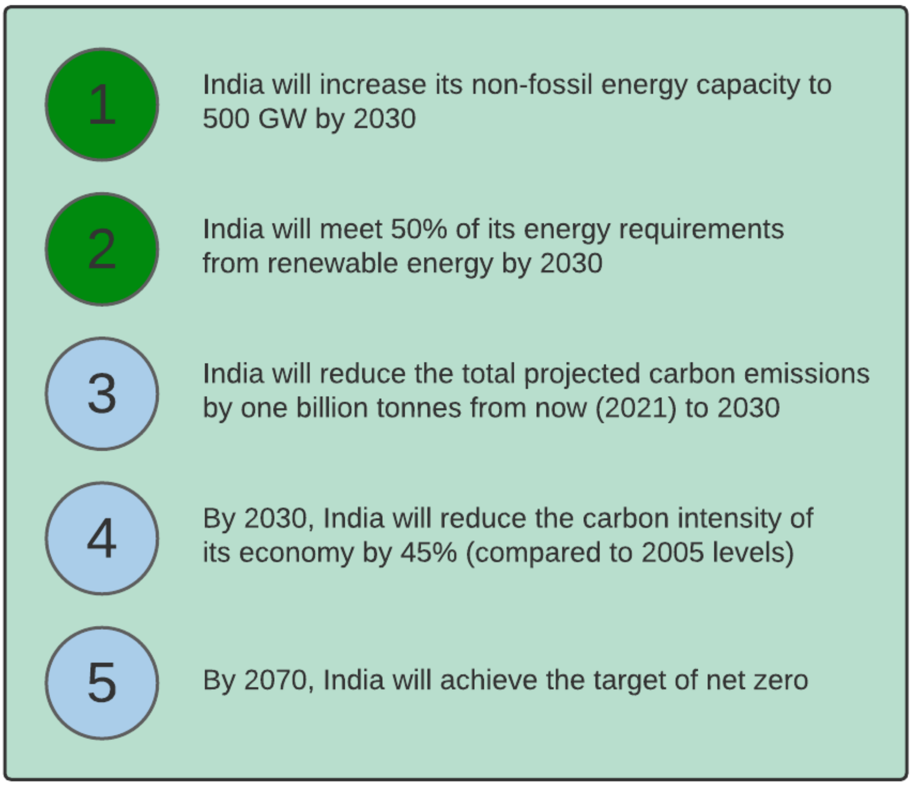


Figure 4: India's COP26 pledges

As pledges 1,2 and 4 are considered the most concrete these are the pledges that will be focused on in this thesis. The following key research questions are formulated: 'Which types of power sector and carbon efficiency improvement scenarios might lead to the fulfillment of India's COP26 pledges (1,2,4)?', 'What are the key factors affecting the outcome?', and 'How likely is each of the studied scenarios and each pledge fulfillment?'. The first research question is studied quantitatively through manipulation of Multi-Regional Input-Output (MRIO) tables. Key factors and sectors will be identified through Structural Decomposition Analysis (SDA). The likelihoods of the scenarios and pledges are assessed qualitatively based on the full analysis of the thesis, previous literature, and public policy discussions.

2 Literature review

2.1 Trade, CBA & PBA

There are two main methods of emission accounting, production-based accounting (PBA) and consumption-based accounting (CBA) [6]. The former includes all emissions generated by meeting the global demand of an economy's products and services, while the latter includes all emissions generated by meeting an economy's demand of global products and services. The distinction between the accounting methods is visualized in Figure 5 using India as a case country.

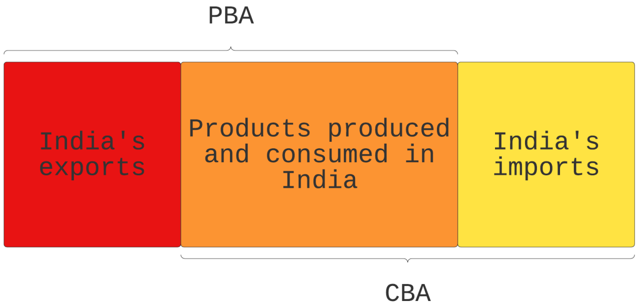


Figure 5: Graphical representation of PBA & CBA

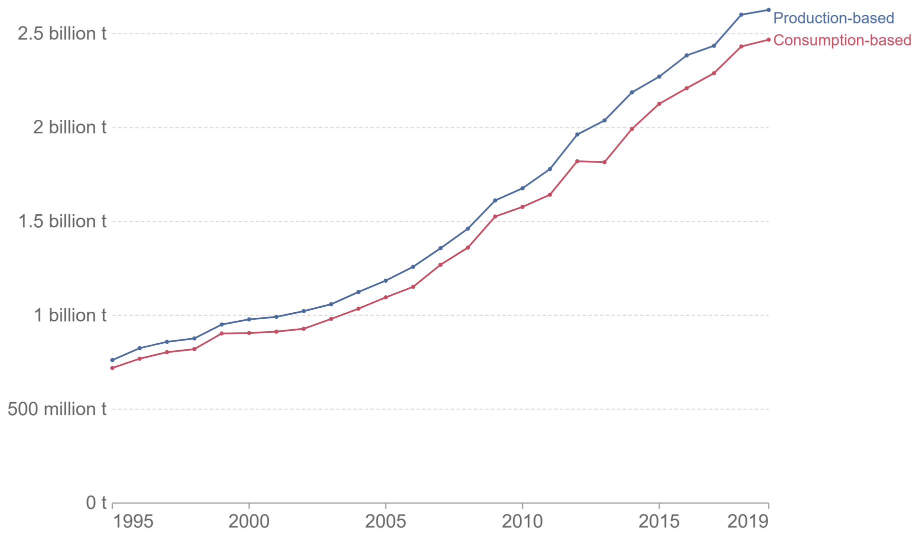


Figure 6: India's CO_2 emissions excluding LULUCF [1]

As both approaches include domestic demand, whether a country's PBA or CBA emissions are the largest depends on its trade balance. India's historical trade numbers show strict larger emissions embodied in exports than imports [1] [7]. Figure 6 presenting India's carbon dioxide (CO_2) emissions applying PBA and CBA confirms the country's position as a net exporter of emissions. This is in line with the general pattern of large emerging economies having larger PBA emissions than CBA emissions [7]. The same goes for countries like Russia and Qatar, who are significant exporters of fossil fuels [1] [7]. Service-based economies such as the United States, Germany, and Japan are on the other hand net emission importers [1] [7]. Historically, most emission and climate policy research analyses have applied PBA [6]. Karakaya et al. argue that this has led to many existing studies being misleading as net importers of emissions have been provided significant advantages [6]. On the other hand, Franzen & Mader found the differences between PBA- and CBA- results to be small [8]. They also argue that applying CBA instead of PBA increases the magnitude of calculation assumptions due to the complexity of MRIO tables, leading to inaccurate results. Hence, they suggest keeping the production-based approach. As a compromise, many researchers choose to apply both accounting methods.

2.2 Energy & electricity

In 2021, Debbarma et al. published a paper analyzing India's sector-wise GHG emissions. They found a remarkable development in the emissions originating from energy processes. In 2001, emissions assigned to the energy sector were estimated to be approximately 1.0 Gt CO_2e, making up about 58% of total emissions [9]. In 2018, the number had increased to approximately 2.4 Gt CO_2e, equivalent to 71% of total emissions. While the emissions assigned to the energy sector increased by 1.4 Gt, the direct emissions assigned to all other sectors (industrial processes, waste, and agriculture, forestry & land use) only increased by a total of about 0.3 Gt. The 2018-shares are in line with the sector-wise worldwide GHG emissions showing that energy processes account for more than 70% of global emissions [10]. This is partly due to extensive use of carbon-intensive energy sources. 83% of global direct energy consumption originated from fossil fuels in 2019 [11]. India was above the world average with 90% [11]. The country's approximated direct energy consumption by source is presented in Figure 7. Due to losses in the production chain, an inefficiency factor has been applied for fossil fuels to better approximate the shares of the different final energy consumption sources. The figure shows an energy mix that in the last decades has been dominated by coal (50-58%), oil (27-34%), gas (6-9%), and hydro (4-8%). Nuclear's share has throughout the period remained at about 1%, while the remaining non-fossil sources have just recently started making an impact.

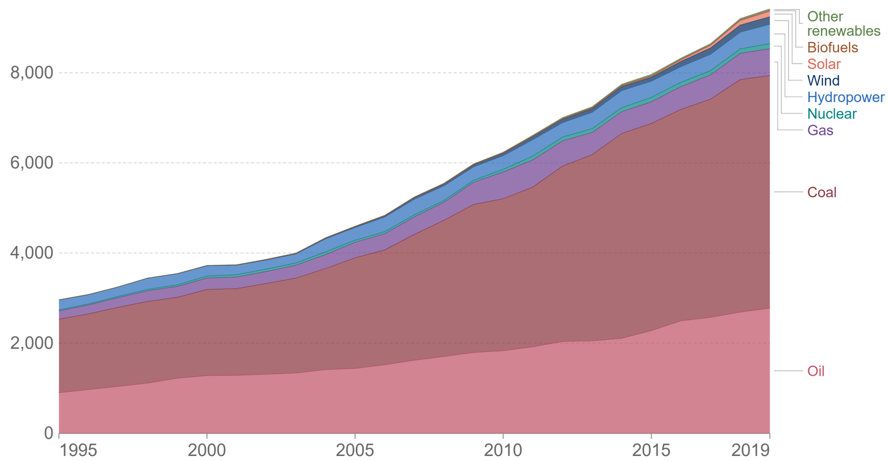


Figure 7: Direct energy consumption by source [TWh] [11]

Debbarma et al.'s finding of the energy sector being responsible for 71% of India's GHG emissions in 2018 must be elaborated further upon. The energy sector is very comprehensive as it includes the indirect energy related emissions of all sectors. As an example, it includes the emissions caused by energy use in industrial processes, which are much larger than the direct emissions of the industry sector. As it is such a broad category, dividing it into subsectors paints a clearer picture. The result is presented in Figure 8, which also includes the remaining sectors analyzed by Debbarma et al. The figure shows the electricity & heat sector becoming the dominating sector of India's emissions in the course of the last decades. In 1995, the 0.37 Gt CO_2e made up 30% of India's total GHG emissions, while the 1.26 Gt CO_2e in 2018 increased the share to 38% [10]. Being the sector with the largest emissions, and thus having the largest mitigation potential, it is natural that the power sector is the focus of India's COP26 pledges.

While the power sector's emissions increased by 240%, the electricity production increased by 270%, from 427 TWh (terawatt-hour) in 1995 to 1579 TWh in 2018 [11]. The relative development reveals a small improvement in the carbon intensity of India's electricity mix, despite a constant fossil share of about 80%. Hence, the improvement is due to carbon efficiency measures, like cleaner and more efficient production processes [12]. Chikkatur et al. found that part of the improvement is due to the implementation of more advanced, international technology instead of the domestically produced, traditional subcritical pulverized coal combustion power plants [12]. Garg & Shukla agree on this finding, but they also argue that switching to less carbon-intensive fuels have had a positive

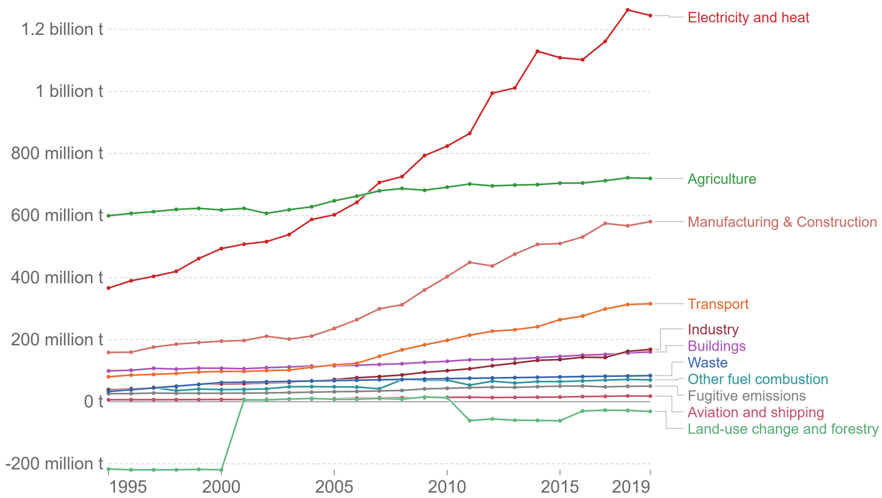


Figure 8: GHG emissions by sector [CO_2e] [10]

effect [13]. They also found that the mitigation potential of introducing carbon capture and storage (CCS) technology in India is considerable. By applying CCS to the five to ten most significant coal-based large point source clusters 3-6 Gt CO_2 could have been mitigated during the period 2010-2030. However, they point out that the scenario is strictly hypothetical, as their analysis indicate that "mitigation will more likely arise from energy efficiency and fuel-mix changes in the short to medium term and CCS technology is likely to penetrate later". This view is shared by Shaw et al., whose study concludes that Indian CCS projects are not expected to begin taking significant effect until after 2030 [14].

Coal's role as the historically most significant power source is clear in Figure 9, which presents India's electricity mix [11] [15]. It is also clear that coal will play a key part in the electricity mix towards 2030. It caused a commotion when the Indian delegation proposed using the term 'phasing down' instead of 'phasing out' when discussing the future of coal-fired power at COP26 [16]. However, the wording was agreed upon and used in the final deal of the conference. Slightly more than a year later, in January 2023, the Indian government noted power generation companies across the country not to retire coal-fired power plants until 2030 [16]. The Central Electricity Authority (CEA), who advises the government on policy matters, informed in a statement that the reason was energy security [16]. The CEA also formulates plans regarding the future electricity systems and have released official 2030 projections. The projected values of installed power capacity by

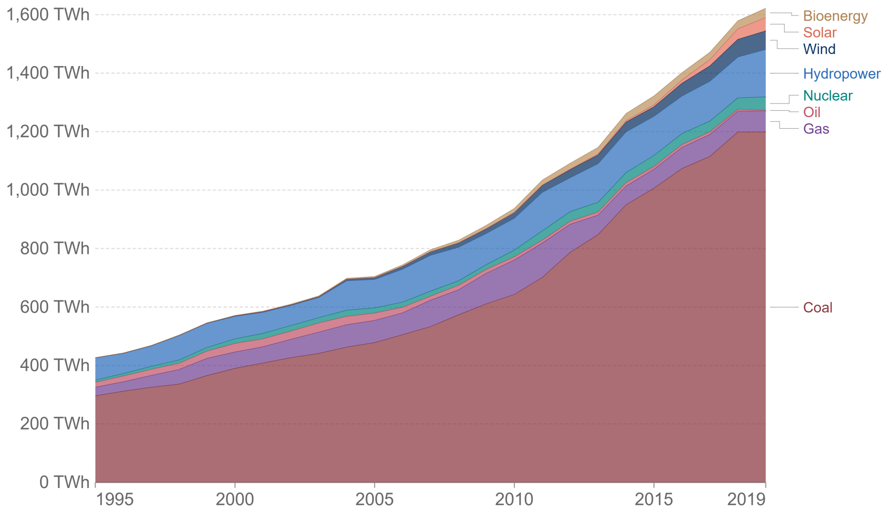


Figure 9: Electricity production by source [TWh] [11] [15]

source are presented in Table 1, which also shows the development from the year 2000. The table shows that India is expected to install additional coal power capacity by 2030. Note that petroleum and biomass & waste are referred to as 'other' in the CEA report, having a total projected value of 25 GW. The shares are estimated based on weight-adjusted projections of the Energy Innovation LLCs Energy Policy Simulator [17] and historical trends [3] [11].

Table 1: Installed power capacity [GW] [5] [15]

Power generation technology	2000	2010	2021	CEA 2030 projections
Coal	63	100	234	267
Gas	10	19	26	25
Petroleum	7	11	14	5*
Nuclear	3	5	7	19
Solar	0	0	50	280
Wind	1	13	40	140
Hydro	24	36	47	61
Biomass & waste	0	3	10	20*
Sum	**108**	**187**	**428**	**817**
Non-fossil fuel power capacity	**28**	**57**	**154**	**520**

* *Other = Petroleum + Biomass & waste = 25 GW. Shares estimated based on other data [3] [11] [17].*

Table 1 shows that hydropower traditionally has been India's standout non-fossil electricity source. It also shows that solar and wind power will take over that role in the future. The CEA explains the expected huge development in renewable energy by cost reductions and increased attention to environmental issues [5]. According to the International Renewable Energy Agency, between 2010 and 2020, the cost of electricity from utility-scale solar photovoltaics (PV) fell 85%, concentrating solar power (CSP) fell 68%, onshore wind fell 56%, and offshore wind fell 48% [18]. The effects of solar and wind power's increased competitiveness compared to thermal power are already prominent. Especially solar power's development stands out, from having a negligible impact in 2010 to having the second largest installed capacity of all power sources in 2021. The CEA's projections show that it is also expected to overtake coal by 2030. The exponential increase in renewable power is expected to make sure India surpasses the goal of 500 GW non-fossil energy capacity by 2030, fulfilling the first of its COP26 pledges. However, according to CEA's estimations, the growth will not be enough to fulfill the second pledge of meeting half of the electricity requirements with renewable power as the share is expected to be 40.0%. Nuclear's share is expected to be 4.5%, leaving 55.5% of the requirements to be met by fossil fuels. The shares are estimated based on a projected 2030 gross electricity generation of 2518 TWh, equivalent to a constant annual growth rate of about 4.4% [11]. Based on the period 1995-2019, the rate is much larger than the global average of 2.9%, but smaller than India's own of 5.7% [11]. However, the Business-as-Usual (BAU) scenario projections of Spencer & Awasthy (2533 TWh [19]), Dasgupta & Sarangi (2352 TWh [20]) and Negi & Kumar (2482 TWh [21]) are all in the same order of magnitude. All three studies point out the relation between electricity consumption and GDP. Spencer & Awasthy found the variations in the projections of economic growth levels to be the largest source of uncertainty affecting the power generation estimates. Dasgupta & Sarangi's study is the only one that specifies that real GDP growth rates are applied. They project India's 2030 GDP to be 4643 billion $US15. Negi & Kumar's main finding concerns energy efficiency. They conclude that energy efficiency measures will play a significant role in guiding electricity consumption pattern by 2030. They specifically mention the use of energy efficient appliances and equipment within the industrial sector having a large impact on power projections.

India's potential gains from energy efficiency measures are studied in detail in Vishwanathan et al.'s report from 2017 [22]. It presents energy efficiency opportunities within several key sectors of India's economy. Among other findings, they identified the electricity industry as a sector with huge potential. India's transmission and distribution losses were in excess of 20% in 2015, significantly above the global average of approximately 9%. Despite an improvement from the 24% in 2011, there are still large efficiency opportunities, and the Indian government has set a target of 15% by 2022 [22]. Implementing supercritical coal-fired power plants - in addition to solar and wind power plants - is mentioned as another measure. Within the agricultural sector, energy efficient pumps are identified as a key factor, while the transport sector should focus on metro rail projects, in addition to increasing the use of electricity and biofuels. The suggested measures within the residential sector include implementation of energy efficient fans, advanced space-cooling systems, light-emitting diodes (LEDs), and cleaner cooking processes. The Perform, Achieve, Trade (PAT) scheme was introduced in 2011 as part of improving the energy efficiency of the industrial sector. It assigns targets to energy-intensive industries and allows trade of energy saving certificates between candidates based on whether they are successful in reaching said targets. Vishwanathan et al. identify developing the scheme further as the measure with the highest potential within the industrial sector.

2.3 Emission, GDP & power projections

The rapid growth in India's emissions has led to a lot of research on the country's future emissions being conducted in the course of the last decade. Table 2 shows a selection of studies' BAU projections of 2030 CO_2 emissions. The studies were selected due to their emission projections being based on expected real GDP growth rates, which are applied to calculate the emission multiplier changes. The 2005 CO_2 emission multiplier of 1.04 kg CO_2 per $US15 was found dividing the 1136.5 megatonnes (Mt) CO_2 emitted (Figure 6, Our World In Data[1]) by the GDP of 1094.3 billion (Figure 2, Our World In Data[2]). The remaining calculations can be found in the attached Excel file 'Emission_multiplier.xlsx'.

Table 2: 2030 CO_2 emission and annual real GDP growth rate projections

Study	**2030 emissions [Mt CO_2]**	**GDP growth rate**	**CO_2 emission multiplier change (2005-30)**
du Can et al.[23]	4005	7% (2015-30)	-33.6%
Parikh et al.[24]	4707	7.44% (2012-30)	-26.9%
Gupta et al.[25]	4160	6.5% (2013-30)	-24.3%
Gupta et al.[26]	4180	6.26% (2013-30)	-20.9%
Vishwanathan et al.[27]	4104	6.93% (2020-30)	-19.1%
Yu et al.[28]	4563	6.22% (2010-30)	-14.4%
Mathur & Shekhar[29]	6498	8.3% (2016-30)	-10.0%
Singh et al.[30]	4568	5.7% (2011-30)	-5.1%
Byravan et al.[31]	5578	6.5% (2012-30)	+1.4%
Shukla et al.[32]	8004*	8% (2015-30)	+15.5%

* *9083 Mt CO_2e when considering all GHGs resulting in an emission multiplier change of -23.2%*

The 2030 GDP projections vary from 4.63 trillion $US15 (Singh et al.) to 6.95 trillion $US15 (Mathur & Shekhar). The median is 5.29 trillion $US15, while the average is 5.60 trillion $US15. The median estimated CO_2 emissions is 4566 Mt CO_2, while the average is 5037 Mt CO_2. The numbers result in a median CO_2 emission multiplier change of -16.8% and a mean of -13.7%. Regardless of tendency measure applied, the emission multiplier change is far off the goal of -45%. However, it must be emphasized that these are BAU projections serving as benchmarks to measure the impact of climate policy actions.

It is noted that the 2005 CO_2 emission multiplier (1.04 kg CO_2 per $US15) is way smaller than the 2005 emission multiplier when including all GHGs (1.77 kg CO_2e per $US15 (Figure 3, Our World In Data[1] [2])). This is due to the impacts of methane (CH_4) and nitrous oxide (N_2O). Their respective shares of India's total GHG emissions were 30.5% and 10.4% in 2005, way larger than the global averages of 18.6% and 6.7%[1]. Garg et al. state in their study on India's GHG emissions that, at the time, the agriculture & livestock sector was responsible for more than 65% of CH_4 emissions and more than 90% of N_2O emissions[33]. While the global CH_4 and N_2O emission shares have remained at relatively stable levels, India's shares have dropped significantly since 2005. The 2019 shares were reported to be 19.6% and 7.8%, close to their respective current global

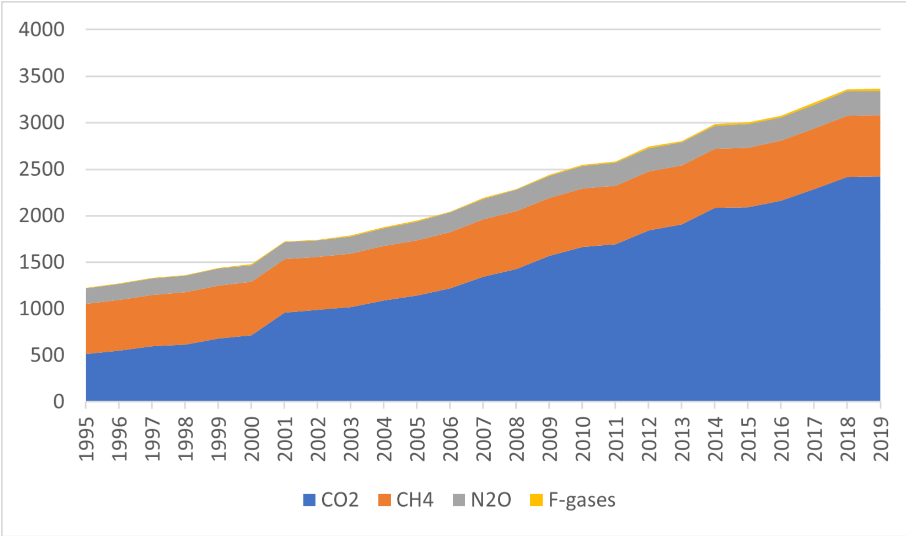


Figure 10: Emissions by GHG [Mt CO_2e]

average shares [1]. The development is illustrated in Figure 10, which shows India's emissions by GHG [1]. It is noted that fluorinated gases (F-gases) only made up 0.4-0.6% of the total annual GHG emissions in the period 2005-2019 [1], and thus can be regarded negligible.

Despite the drastic development in India's GHG mix, nine out of the ten studies presented in Table 2 only consider CO_2. Being the only paper considering all GHGs, Shukla et al.'s study also illustrates the difference the choice of GHGs makes on the emission multiplier change. When only considering CO_2, the emission multiplier is projected to increase by 15.5%, while it is projected to decrease by 23.2% when considering all GHGs. This is a result of a predicted continuation of the development of non-CO_2 GHG emissions described above. While CO_2 emissions increased by 121% (+1.51 Gt) in the period 2005-2019, CH_4 and N_2O emissions only increased by 10.6% (+63.2 Mt CO_2e) and 28.7% (+58.4 Mt CO_2e) respectively [1]. Hence, the difference in the emission multiplier changes can be seen as a result of the non-CO_2 GHG emission growth rate being so much smaller than the one of CO_2. This point can be further illustrated by a hypothetical scenario in which the non-CO_2 emissions presented in Shukla et al. are added to the study with the smallest CO_2 emission results, du Can et al. Dividing the total GHG emissions of 5084 Mt CO_2e with du Can et al.'s projected 2030 GDP results in an emission multiplier change of -50.6%. Despite the studies' disproportionate CO_2 emission growth rates, also du Can et al.'s emission multiplier change becomes way larger when not only considering CO_2. Hence, it seems it will be easier to fulfill the pledge of 45% emission multiplier decrease if all GHGs are considered. In the official statement of pledge 4, the wording 'emission intensity' is used, but which emissions is not specified [4]. However, in India's third Biennial Update Report published in 2021, all GHGs were included in a statement concerning the emission intensity of GDP dropping by 24% from 2005 to 2016 [34]. Hence, it must be assumed that all GHGs should be included when evaluating the pledge. Note that emissions from LULUCF were excluded in the report's calculations of the emission multiplier change.

While not explicitly mentioning the COP26 pledges, Bakir et al. do consider all GHGs in their study on India's emission trajectories published in August 2022 [35]. They apply five metaheuristic algorithms using regression-generated future values of electricity generation, GDP, and population numbers as inputs to project GHG emissions. The 2030 results are in the range of 4.8 to 5.2 Gt CO_2e, with a mean of 5.12 Gt CO_2e. It is specifically mentioned that all costs in the study are expressed in constant $US15 but it is not stated whether the same goes for the GDP projections. Hence, the study is not included in Table 2. However, using the mean GHG emission projection and assuming that the 4.28 trillion USD used as input in 2030 are in constant $US15, the emission multiplier decrease will be 32.8%. Bakir et al.'s regression-generated electricity projections revealed a 2030 renewable electricity requirement share of only 17.1%, far off the goal of 50%. However, it must be mentioned that a linear approach was used to obtain the results, which is not in line with the CEA's expectations of exponential growth in renewable energy [5].

All studies presented in Table 2 were published prior to COP26, and hence, do not directly evaluate the pledges presented in Figure 4. However, they all include a more or less comprehensive section on the power sector. The 2030 estimates of annual electricity generation range from about 2100 TWh to 3300 TWh, which is in line with the findings in subsection 2.2. Naturally, the power requirements increase with increasing projected GDP. Several studies indicate that India is likely to achieve a total non-fossil power capacity of between 45% and 59% by 2030. All studies mention decelerating the growth in new installed coal power capacity as key in offsetting further increase in emissions. The projections of the 2030 coal power capacity range from 160 GW to 270 GW.

Only one study explicitly focusing on the pledges has been found. Das et al. published in January 2023 a paper exploring the role of different technologies in achieving the power sector goals [36]. They project a total 2030 power capacity of 861 GW, of which 510 GW is non-fossil, including 280 GW of solar, 140 GW of wind, 52 GW of hydro, 18 GW of nuclear, and 18 GW of other renewables. Hence, pledge 1 concerning 500 GW non-fossil power capacity will be fulfilled. However, the projected 319 GW of coal power capacity will make sure pledge 2 concerning meeting 50% of the electricity requirements with renewable power will not be fulfilled, as it will generate more than 65% of the total projected electricity requirements of 3404 TWh. In the literature review section of Das et al.'s paper, they criticize many of the studies in Table 2 for not considering the feasibility of the projected high presence of Variable Renewable Energy (VRE) sources. Hence, their research focused on establishing the feasibility of large-scale VRE integration in India. They found that storage technologies will be essential in the future, especially towards reaching net zero emissions by 2070. Due to lower expected costs, battery storage will be preferred above hydro pump storage. However, they found that neither storage technology will play a significant part before 2030. Agreeing with Garg & Shukla and Shaw et al.'s findings, Das et al. also concluded that CCS projects will not begin taking significant effect until after 2030.

Dasgupta & Sarangi's study - referred to in subsection 2.2 - was published shortly after COP26 but does not mention the pledges [20]. It does however forecast the 2030 electricity mix. Of the projected total electricity requirements of 2352 TWh, renewables will have a share of 33%, resulting in pledge 2 not being fulfilled. The 33% are shared between solar (16%), wind (9%) and hydro (8%), while bioenergy is not considered. Nuclear power's share is less than 2%. Due to a total installed capacity of approximately 200 GW, coal's share is expected to be 63%. Making up 62% of the total installed capacity of 567 GW, the cumulative non-fossil power capacity is projected to be 357 GW. Hence, pledge 1 will also not be fulfilled according to Dasgupta & Sarangi's results.

2.4 Manipulation of MRIO tables & SDA

Most of the studies presented in Table 2 apply a magnitude of assumptions related to macroeconomics, sectoral demands, energy mix, technology, and costs, and analyze the outcome based on various criteria. Still, there are large variations in the methodological frameworks applied. The design approaches include bottom-up optimization (AIM/ENDUSE [27], ANSWER-MARKAL [29], IMRIT [31]), bottom-up simulation/stock accounting (LBNL India Dream [23]), general and partial equilibrium models (GCAM India [28], Multi-sectoral [30], AIM-CGE [32]), top-down optimization (IRADe-Neg50 [24]), and hybrid models (AIM/ENDUSE + IMACLIM [25] [26]). Bakir et al. and Das et al. also apply bottom-up optimization models [35] [36]. The diversity of methods is overwhelming but also welcomed as it strengthens the collective numerical basis of the projections. Beaufils & Wenz suggest applying yet another methodological framework in the context of forecasting [37]. Their research shows that adjusting a MRIO table such that it meets prescribed GDP developments can "over a period of a few years, convincingly reproduce the quantitative trends of the world economy, while being rather conservative with regard to structural changes". Hence, their results indicate that manipulating MRIO tables is a suitable approach in analyzing India's 2030 pledges, as it is not that far into the future.

To further break down the sector-wise development needed in order to fulfill the pledges, SDA methodology can be applied. It builds on Wassily Leontief's input-output demand-pull model and has become an increasingly more applied technique within emission and energy accounting throughout the last decades [38] [39]. The method aims to break down observed changes into key physical and economic parameters in an input-output table. The decomposition allows for easier identification of the main drivers behind physical variable changes and is therefore a suitable approach in analyzing emission and energy trends.

There are several different SDA methods, the Dietzenbacher & Los (D&L) method being the most popular [39]. However, it is also one of the most computation-intensive. n decomposition factors yield $n!$ decomposition forms. As an example, breaking down emission change into five determinants results in $5! = 120$ decomposition forms. As a consequence of its computation requirements, many researchers prefer the lighter version of the method. The 'approximate D&L method' would simply yield $n = 5$ decomposition forms.

While SDA is generally considered an effective tool in analyzing environmental issues, it has also received a lot of criticism. Baranov et al. problematize researchers uncritical use of the method in terms of choice of decomposition factors and the resulting ambiguity of the corresponding interpretations [40]. In clearer terms, the large variations in how different studies choose to break down a problem leads to incoherency. Differences in methodology and data also add to the issue. An illustrative example is the differences found in the studies of Arto et al. [41] and Feng et al [42]. They both analyzed the drivers of the changes in China's consumption-based GHG emissions in the period 1995-2008 applying SDA methodology. While they used the same database - the World Input-Output Database (WIOD) - subsequently agreeing on the overall carbon footprint change, there were large variations in terms of underlying drivers. Arto et al. found that the increase in final demand volume contributed with 5 Gt CO_2e, while Feng et al. found the same number to be 16 Gt CO_2e. Arto et al. stated that the emission increase was offset by approximately 3 Gt CO_2e due to carbon efficiency measures, while Feng et al. claimed the same number to be 15 Gt CO_2e. While agreeing that production structure had limited impact on the emission changes, the deltas they found had opposite signs. Arto et al. also chose to include import structure in their SDA, while Feng et al. included final demand structure. Both decomposition factors had limited impacts. Despite having the same starting point and data, the studies' conclusions concerning the magnitude of the driving factors varied greatly due to methodological differences. This illustrates how results obtained through SDA must be handled critically.

Despite being the third largest emitter of GHGs globally [1], only a few recent in-depth SDA studies focusing solely on India's production-based emissions have been found. Zhu et al.'s study from 2018 analyzes the drivers of India's production-based CO_2 emissions in the period 2007/08-2013/14 [43]. Applying the D&L method, they found that final demand and production recipe increased the emissions by 510 Mt CO_2 and 286 Mt CO_2, respectively. Final demand composition and carbon efficiency decreased the emissions by 101 Mt CO_2 and 81 Mt CO_2, respectively. The resulting 0.6 Gt emission increase was mainly driven by private consumption changes, primarily due to larger per capita income levels.

While Zhu et al. highlight efficiency measures within the energy sector as an important factor affecting emissions, it is not directly included as a decomposition factor in their study. This is pointed out by Wang et al. in their paper analyzing India's production-based CO_2 emission changes in the period 2000-2014 applying the D&L method [44]. They chose to split 'carbon efficiency' into three determinants: 'emission coefficient', 'energy structure' and 'energy intensity'. While energy structure had a negligible effect (+12 Mt CO_2), energy intensity (+184 Mt CO_2) had significant impact on the emission changes. Lack of funds to improve the outdated power generation technology was identified as the main cause of the positive delta. Waste of electricity resources due to cheap power is mentioned as another reason. This is a result of the governmental subsidies which are meant to improve the competitiveness of export-oriented companies by lowering their production costs. The increase due to changes in the energy sector was partly offset by changes in 'emission coefficient' (-50 Mt CO_2), but it was not enough to prevent that the development in carbon efficiency in total (+146 Mt CO_2) moved in the wrong direction. Wang et al. also found per capita final demand (+981 Mt CO_2) and population (+257 Mt CO_2) to have significant positive deltas, while changes in final demand structure had negligible impacts. Production recipe (-249 Mt CO_2) was the only factor having a significant offsetting effect, resulting in a total emission increase of 1.1 Gt CO_2. Agreeing with Zhu et al., increasing household consumption - especially after the global financial crisis in 2008 - was the main driver of the emission increase.

Applying the approximate D&L method, Dwivedi & Soni's paper from 2022 analyzes the changes in India's production-based CO_2 emissions between 2000 and 2016 [45]. They chose to split the 16-year period into two eight-year periods to get more detailed SDA results. They also chose to divide 'final demand' into four categories: household consumption (2000-08: +180 Mt, 2008-16: +611 Mt), government consumption (2000-08: +31 Mt, 2008-16: +22 Mt), Gross Fixed Capital Formation (GFCF) (2000-08: +273 Mt, 2008-16: +274 Mt), and exports (2000-08: +210 Mt, 2008-16: +300 Mt). Agreeing with the previously presented papers, household consumption was the category with the largest total delta, yet both GFCF and exports had significant impacts. Dwivedi & Soni also found that both carbon efficiency (2000-08: -262 Mt, 2008-16: -126 Mt) and production recipe (2000-08: +43 Mt, 2008-16: -259 Mt) significantly contributed to decelerating the emission growth, especially in the second period.

Malik & Lan's study from 2016 include a part on the drivers of India's national CO_2 emissions (PBA emissions excluding exports) from 1990 to 2010 [38]. Applying the D&L method, their SDA results show that per capita demand contributed with approximately 1.8 Gt CO_2, while carbon efficiency was the only significantly offsetting factor (-1.3 Gt CO_2). Population increase (+0.3 Gt CO_2) and production recipe (+0.3 Gt CO_2) had relatively small positive deltas, while final demand destination and composition had negligible impacts.

An SDA study concerning India's renewable energy development has also been found. In a paper published in 2021, Wang & Liu applied the approximate D&L method to analyze the production-based renewable energy use between 2000 and 2014 [46]. They found that the continuous growth from 561 TWh in 2000 to 967 TWh in 2014 was driven by the increased final demand (+1018 TWh) of India's products and services. The increase was however heavily offset by changes in energy efficiency (-555 TWh). Production recipe (-57 TWh) also had a small offsetting effect. Like the conclusions of the papers on emission change, Wang & Liu found that increased domestic household consumption (+428 TWh) also was the main driver of the increased renewable energy use.

2.5 Aim & scope of the thesis

While the literature review revealed many studies on India's past and predicted future emissions and electricity use, they all only indirectly or partly evaluate the COP26 pledges. Most of them also only include CO_2 emissions, which is not sufficient when evaluating the emission multiplier pledge [34]. Subsection 2.3 highlights the significant impact of excluding CH_4 and N_2O in India's emission multiplier calculations, and hence, they will be included in this study. As India's COP26 pledges are interpreted to be exclusively focused on domestic factors, PBA will be the only applied accounting method. By adopting a similar approach as suggested by Beaufils & Wenz [37], MRIO tables will be manipulated in order to forecast emissions and electricity use. The future MRIO tables will be based on India's expected 2030 GDP and the historical trends of its economy. In addition, as the literature review revealed the power sector's increased effect on India's emissions, several scenarios will be made to represent different levels of integration of renewable power solutions. The CEA's estimated 2030 installed power capacities presented in Table 1 [5] will be used as a benchmark capacity mix projection, in which other scenarios will build on. Through this new approach, the thesis will provide new insights into India's path towards fulfilling its COP26 pledges.

3 Materials & Method

Note that subsection 3.3 in part can be considered a continuation of the method section in the author's Industrial Ecology project work conducted in the autumn semester 2022 [47]. The same goes for subsection 3.5. The project considered the underlying mechanisms of decreased GHG emissions in industrialized countries using Germany as a case country.

3.1 Research design

The research was conducted in three main phases: (a) the construction of the projected 2030 MRIO tables and stressor vectors, (b) the construction of the SDA model applied to analyze the driving factors of emission and energy (electricity) use changes, and (c) the handling and analysis of the results. Figure 11 presents a simplified flowchart of the research design. The components of the design are elaborated upon in the following sections. Note that case-specific prerequisites and modelling choices are elaborated further upon in subsection 3.6.

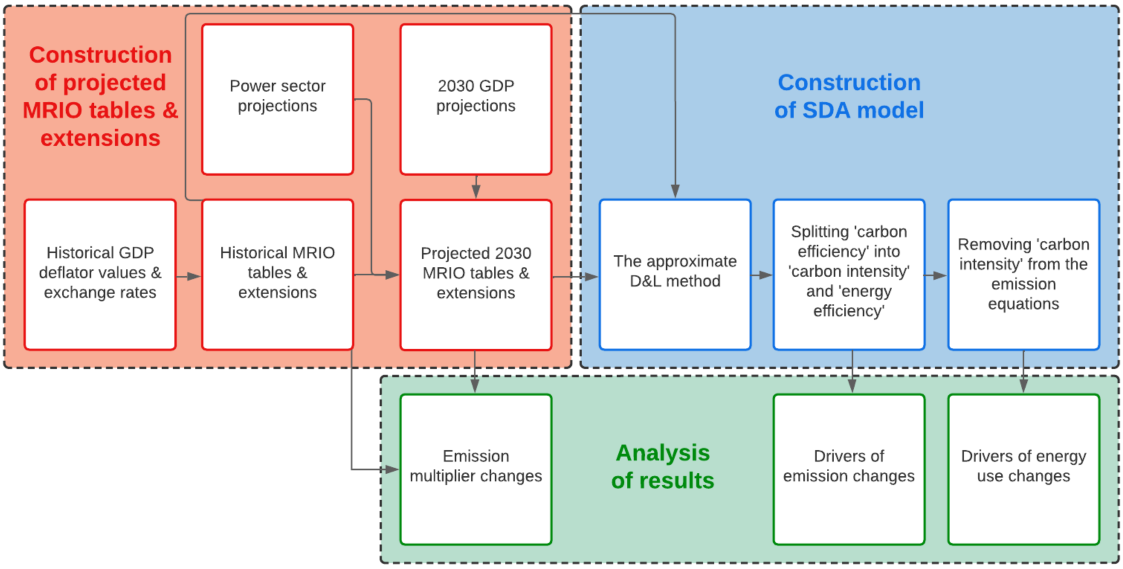


Figure 11: Flowchart of research design

3.2 Research materials

The historical MRIO tables and extensions originate from version 3.8 of EXIOBASE, which is one of the most widely recognized global MRIO databases [48]. The sets include data from 49 countries, India being one of them. For every country, all products and services are aggregated into 200 sectors. Due to EXIOBASE data only being provided for year 1995 through 2015, three base years are selected to represent the development throughout the 20-year period: 1995, 2005, and 2015.

To be able to directly compare the MRIO tables, the values need to be adjusted for inflation and currency fluctuations. The EXIOBASE data is originally given in Euros of the current year. Hence, to convert the tables to constant 2015 US dollars ($US15), historical Indian GDP deflator values [49] and exchange rates (Euros to Indian Rupees & Euros to US dollars) [50] are applied. Firstly, the tables are multiplied by the exchange rate of the current year to obtain local currency. Secondly, they are multiplied by the GDP deflator value of 2015, and divided by the GDP deflator value of the current year to obtain constant 2015 prices in local currency. Then, they are divided by the 2015 exchange rate to be converted to constant 2015 prices in Euros. Lastly, they are multiplied by the 2015 exchange rate between Euros and US dollars to be expressed in constant $US15. The inflation and currency fluctuation adjusted multiplier for year i, k_i, can thus be expressed as

$$k_i = EUR - INR_i \times \frac{GDPdef_{2015}}{GDPdef_i} \times \frac{EUR - USD_{2015}}{EUR - INR_{2015}}, \quad (1)$$

where $EUR - INR_i$ is the exchange rate of Euros to Indian Rupees in year i, $GDPdef_i$ is the Indian GDP deflator value in year i, and $EUR - USD_{2015}$ is the exchange rate of Euros to US dollars in 2015.

3.3 MRIO methodology

Three matrices make up the basis of MRIO calculations: the final demand matrix, **Y**, the inter-industry flow matrix, **Z**, and the environmental extension matrix, **F**. After being multiplied with their respective k-values, and thus being expressed in $US15, the **Y**- and **Z**-matrices of the different years are directly comparable. The total production-based demand vector in year i, y_i, can be found summing the rows of domestic final demand and RoW (rest of world) final and intermediate demand[51]:

$$y_i = \sum \mathbf{Y_{i,dom}} + \sum \mathbf{Y_{i,RoW}} + \sum \mathbf{Z_{i,RoW}} \quad (2)$$

The GDP of year i expressed in $US15 is simply the sum of y_i:

$$GDP_i = \sum y_i \quad (3)$$

An economy's total output, the x-vector, is defined as

$$x = \mathbf{Y} \times i_Y + \mathbf{Z} \times i_Z, \quad (4)$$

where i_Y and i_Z are vectors with lengths equaling the row-dimension of their corresponding matrix. As the vectors simply are applied to sum over each of the rows of the **Y**- and **Z**- matrices, they only consist of 1's.

L is the Leontief inverse matrix. It can be considered a production recipe as it represents the interactions between the different sectors of an economy[52]. **L** is defined as

$$\mathbf{L} = (\mathbf{I} - \mathbf{Z} \times \hat{x}^{-1})^{-1} \quad (5)$$

I is the identity matrix with dimensions equal to those of **Z**. The 'hat'-symbol ($\hat{}$) indicates that a vector is diagonalized, while $^{-1}$ indicates an inverse of a matrix. Note that due to both x and **Z** being influenced by k, the inflation and currency fluctuation adjustment is cancelled out when calculating **L**. In other words, **L** is unaffected by k. The same is not the case for the stressor matrix, **S**. It must be divided by k to correctly present the stressor levels per unit output of a sector:

$$\mathbf{S} = \frac{1}{k} \times \mathbf{F} \times \hat{x}^{-1} \quad (6)$$

S consists of a great quantity of stressor vectors, and the vectors that are of interest must be extracted. The 'carbon efficiency' vector, q, is constructed extracting, weighing, and adding the vectors containing the relevant GHGs. The vectors are weighed to present q in CO_2e per unit output of a sector (x). To construct the 'energy efficiency' vector, e, the 'Energy Carrier Net' vector is extracted from **S**. 'Energy Carrier Net' is the amount of energy - including all fuels and activities - consumed per unit output of a sector. e is presented in terajoule (TJ) per unit output of a sector (x). By dividing each element of q with its corresponding element in e, the 'carbon intensity' vector, c, expressed in kg CO_2e per TJ is found:

$$c = \frac{q}{e} \tag{7}$$

As PBA only considers domestic production factors, these are extracted from **L**, q, c and e. Applying Equation 7, the production-based emissions in year i can be found as

$$D_{PBA,i} = \hat{q}_{dom,i} \times \mathbf{L_{dom,i}} \times y_i = \hat{c}_{dom,i} \times \hat{e}_{dom,i} \times \mathbf{L_{dom,i}} \times y_i \tag{8}$$

Energy use is simply calculated excluding c from Equation 8:

$$EU_{PBA,i} = \hat{e}_{dom,i} \times \mathbf{L_{dom,i}} \times y_i \tag{9}$$

The electricity mix of year i can be found extracting the relevant electricity generation sectors from Equation 9.

Naturally, as a consequence of k being cancelled out through **S** being divided by k, **L** being unaffected by k, and y being multiplied by k, both emissions and energy use are unaffected by inflation and currency fluctuation adjustments.

Lastly, the emission multiplier of year i, M_i, is found dividing the production-based emissions by the GDP:

$$M_i = \frac{D_{PBA,i}}{GDP_i} \tag{10}$$

3.4 Projecting MRIO tables & extensions

Due to 'division by zero'-errors, growth rates cannot by directly applied to forecast 2030 values. Instead, the adjusted 2015 **Y**- and **Z**-matrices are used as a basis and compared to the averages of the adjusted 1995- and 2005-matrices to represent economic growth:

$$\mathbf{Y_{2030}} = \mathbf{Y_{2015}} + b \times (\mathbf{Y_{2015}} - \frac{\mathbf{Y_{1995}} + \mathbf{Y_{2005}}}{2}) \tag{11}$$

$$\mathbf{Z_{2030}} = \mathbf{Z_{2015}} + b \times (\mathbf{Z_{2015}} - \frac{\mathbf{Z_{1995}} + \mathbf{Z_{2005}}}{2}) \tag{12}$$

b is an economic growth constant, which is adjusted until the GDP requirements (Equation 3) are met. If a sector has negative growth leading to negative demand, the sector's output is reset to the corresponding 2015-value divided by b. y_{2030} follows from Equation 2 and $\mathbf{L_{2030}}$ is found applying Equation 5. c and e are assumed to have linear developments towards 2030:

$$c_{2030} = c_{2015} + (c_{2015} - \frac{c_{1995} + c_{2005}}{2}) \tag{13}$$

$$e_{2030} = e_{2015} + (e_{2015} - \frac{e_{1995} + e_{2005}}{2}) \tag{14}$$

Note that by applying Equation 11-14, every sector is given its own individual projected growth rates towards 2030. This ensures that the sectors with increasing outputs towards 2015 will continue growing, while the sectors with decreasing outputs towards 2015 will continue shrinking. The same goes for the sectors' corresponding stressor level developments.

The different 2030 scenarios will be built around varying levels of integration of renewable energy solutions. This will be done through manipulating the different electricity solution sectors in $\mathbf{Y_{2030}}$

and $\mathbf{Z_{2030}}$ until Equation 9 shows the prescribed electricity mix. Note that as a result of editing $\mathbf{Y_{2030}}$ and $\mathbf{Z_{2030}}$, b in Equation 11 and Equation 12 must be adjusted to remain at the required GDP level. y_{2030} and $\mathbf{L_{2030}}$ are naturally also affected by the changes in $\mathbf{Y_{2030}}$ and $\mathbf{Z_{2030}}$. c_{2030} and e_{2030} are kept at the same levels if not otherwise is stated.

3.5 SDA

The approximate D&L method[53] is applied to find the change in production-based emissions between year i and j:

$$\begin{aligned}\Delta D_{PBA,i,j} &= D_{PBA,i} - D_{PBA,j} \\ &= \hat{c}_{dom,i} \times \hat{e}_{dom,i} \times \mathbf{L_{dom,i}} \times y_i - \hat{c}_{dom,j} \times \hat{e}_{dom,j} \times \mathbf{L_{dom,j}} \times y_j \\ &= \Delta\hat{c}_{dom,i,j} \times \hat{e}_{dom,i} \times \mathbf{L_{dom,i}} \times y_i \\ &+ \hat{c}_{dom,j} \times \Delta\hat{e}_{dom,i,j} \times \mathbf{L_{dom,i}} \times y_i \\ &+ \hat{c}_{dom,j} \times \hat{e}_{dom,j} \times \Delta\mathbf{L_{dom,i,j}} \times y_i \\ &+ \hat{c}_{dom,j} \times \hat{e}_{dom,j} \times \mathbf{L_{dom,j}} \times \Delta y_{i,j}\end{aligned} \tag{15}$$

Applying the approximate D&L method ensures that the emission changes are decomposed into four contributions. The different decomposition factors' contributions are functions of their respective deltas. As an example, in the first term, $\Delta\hat{c}_{dom,i,j}$ is applied, and hence, this term constitutes the contribution to the emission change caused by the change in carbon intensity between year i and j.

The change in production-based energy use between years i and j is calculated in a similar manner:

$$\begin{aligned}\Delta EU_{PBA,i,j} &= EU_{PBA,i} - EU_{PBA,j} \\ &= \hat{e}_{dom,i} \times \mathbf{L_{dom,i}} \times y_i - \hat{e}_{dom,j} \times \mathbf{L_{dom,j}} \times y_j \\ &= \Delta\hat{e}_{dom,i,j} \times \mathbf{L_{dom,i}} \times y_i \\ &+ \hat{e}_{dom,j} \times \Delta\mathbf{L_{dom,i,j}} \times y_i \\ &+ \hat{e}_{dom,j} \times \mathbf{L_{dom,j}} \times \Delta y_{i,j}\end{aligned} \tag{16}$$

3.6 Research process & case-specific modelling choices

The literature review revealed a lack of studies including non-CO_2 GHGs in the assessment of India's future emissions. It also showed CH_4 and N_2O's significant contributions to India's historical total emissions, highlighting their impact on the emission multiplier. In addition, all GHGs were included in India's third Biennial Update Report, which included a statement concerning the declining emission intensity of India's GDP[34]. Emissions from LULUCF were not included in the report's emission multiplier calculations and will thus not be considered in this thesis. The literature review also revealed F-gases as a negligible source of emissions compared to the other GHGs. Hence, three GHGs will be included in this study: CO_2, CH_4, and N_2O. **S** contains six CO_2-vectors, eleven CH_4-vectors, and two N_2O-vectors. In order to present q in CO_2e, CH_4- and N_2O-vectors are multiplied by 28 and 265, respectively (AR5, GWP100-values[54]). As the literature review revealed that energy storage and CCS technology are not expected to have significant effects prior to 2030 neither will be focused on in this thesis.

In accordance with Baranov et al.'s critique, it is chosen to limit the number of SDA decomposition factors. q is split into c and e to reflect the importance of energy efficiency. **L** is included to capture the interaction changes between the different sectors of the economy, while y represents economic growth. The 2030 GDP is projected using two different approaches. India's Chief Economic Advisor, Venkatramanan Anantha Nageswaran, stated in January 2023 that India is likely to become a $7 trillion economy by 2030[55]. Assuming a constant development in GDP deflator values[49] and exchange rates[50] using the period 2016-2023 as reference, this is equal to 5171 billion $US15. According to S&P Global Market Intelligence, India's real GDP growth is expected to average 6.34% annually in the period 2021-2030 [56]. This results in a 2030 GDP of 4747 billion $US15 [2]. The average of the two projected GDPs, 4959 billion $US15, is used in the calculations of this thesis. Compared to the results of the studies presented in Table 2, this seems a reasonable estimate.

Five different scenarios representing various levels of renewable power integration and energy efficiency are constructed. The first, the BAU scenario, assumes a continuation of the power mix development of the last decades. In other words, the electricity mix is simply extracted applying Equation 9 on the 2030 tables and extensions gathered with Equation 11-14 without further manipulation. The second scenario, the CEA scenario, uses the BAU scenario as a basis and integrates the CEA's 2030 power capacity projections presented in Table 1 [5]. As the literature review revealed that the electricity mix projected by the CEA is assumed to fulfill pledge 1 (500 GW of non-fossil fuel electricity capacity) but not pledge 2 (50% of electricity requirements from renewable sources), a third scenario in which both pledges will be fulfilled is constructed. The power sector goals (PG) scenario also builds on the BAU scenario but integrates a hypothetical electricity mix designed to achieve pledge 2. The two last scenarios, the CEA45%a- and b- scenarios, both build on the CEA scenario but introduces further carbon efficiency measures based on different assumptions to achieve pledge 4. The reason for using the CEA scenario as reference is due to it being considered the most feasible of the first three scenarios. The details of the different scenarios will be elaborated further upon in section 5. In accordance with the CEA's projections, the benchmark electricity demand to be met in 2030 is 2518 TWh [5]. The electricity generation outputs of scenarios 2 and 3 will equal this number, while scenarios 1 and 4/5, due to different energy efficiency levels, will have higher and lower electricity generation outputs, respectively.

3.7 Inputs for power sector projections

The following section presents the inputs used in projecting India's 2030 power generation capacities and electricity mix.

Figure 12 shows the annual values of TWh generated per GW installed capacity of India's projected significant future power generation technologies [5]. As for Table 1 (CEA/Ember [5] [15]), these include coal, nuclear, gas, bioenergy (biomass & waste), hydro, other fossil (petroleum), wind and solar. The values are calculated dividing the historical data of electricity production (Figure 9, Our World In Data/Ember [11] [15]) by installed capacity (Table 1, Ember [15]), and are based on the years 2000-2021. The exception is solar power that is based on the period 2010-2021 due to it being a negligible electricity source in India prior to 2010 [15]. The calculations can be found in

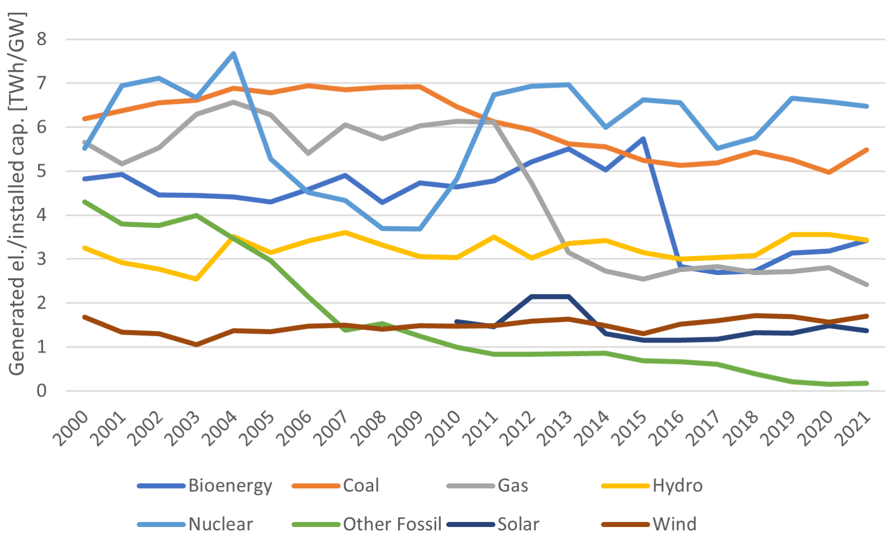


Figure 12: Annual generation/capacity [TWh/GW]

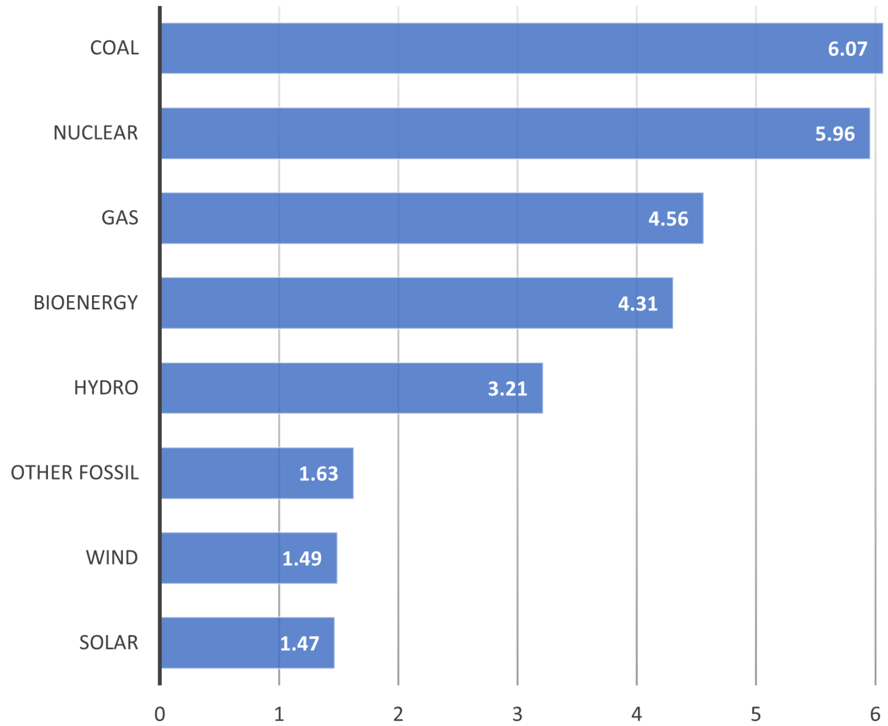


Figure 13: Average generation/capacity [TWh/GW]

the attached Excel file 'India2030_power.xlsx'. Figure 12 is presented to emphasize the variations in outputs, even for "stable" generation technologies like coal and nuclear power. The variations occur due to a number of reasons: changes in demands, supplies and costs, climate and weather, efficiency measures, scheduled maintenance, output reductions, etc. To account for the fluctuations, the average outputs of the power generation technologies are presented in Figure 13. The figure clearly illustrates wind and solar power's unreliability issues as coal and nuclear power are four times as effective, while gas and bioenergy are about three times as effective. This is simply due to thermal power being a more predictable source of electricity. Hydro power is also more than twice as effective as wind and solar power as it is more stable due to the possibility of storing water in reservoirs.

Table 3: Applied energy efficiency factors by scenario

Power generation technology	**BAU**	**CEA**	**PG**	**CEA45%a**	**CEA45%b**
Coal	1.159	1.000	1.000	0.960	1.030
Gas	1.159	1.000	1.000	0.960	0.407
Petroleum	1.159	1.000	1.000	0.960	0.669
Nuclear	1.159	1.000	1.000	0.960	1.049
Solar	1.159	1.000	1.000	0.960	0.669
Wind	1.159	1.000	1.000	0.960	0.669
Hydro	1.159	1.000	1.000	0.960	0.905
Biomass & waste	1.159	1.000	1.000	0.960	1.138
Overall	**1.159**	**1.000**	**1.000**	**0.960**	**0.907**

Table 3 shows the energy efficiency factors applied for each power generation technology by scenario. The factors are calculated using the CEA scenario as a benchmark projection. A value below 1 indicates an energy efficiency improvement, while a value in excess of 1 indicates an energy efficiency drop. The construction of the table will be elaborated further upon in subsection 5.1. The values of Figure 13 are divided by their corresponding factors in Table 3 and combined with the specifications and assumptions mentioned above to construct the power sector scenarios in Excel ('India2030_power.xlsx').

4 Background analysis

The following section discusses the historical emission and electricity use results retrieved applying EXIOBASE data. The discussion of the observed development between 1995 and 2015 will be used to justify methodological choices when constructing and analyzing 2030 scenarios.

The production-based emissions by demand category for the period 1995-2015 are presented in Figure 14. The emissions increased from 1.50 Gt CO_2e in 1995 to 1.95 Gt CO_2e in 2005 and 3.00 Gt CO_2e in 2015. The development is in line with India's GHG emission trend as presented by Our World in Data in Figure 1 (1995: 1.44 Gt, 2005: 1.94 Gt, 2015: 3.06 Gt)[1].

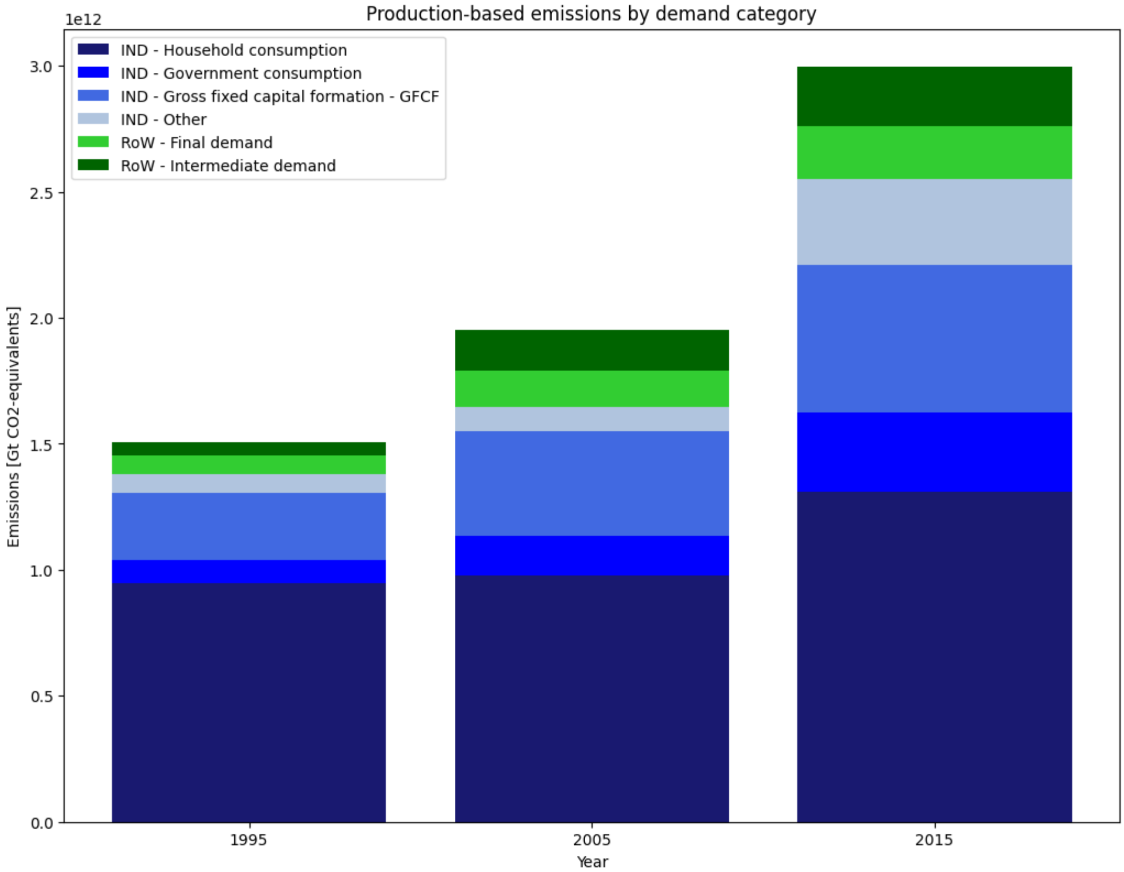


Figure 14: Production-based emissions, 1995-2015 [Gt CO_2e]

Agreeing with the general finding in the SDA literature review, household consumption (+0.37 Gt) was the main driver of the increased emissions during the 20-year period. However, all demand categories had significant emission increases (GFCF: +0.32 Gt, exports: +0.32 Gt, other: +0.26 Gt, government consumption: +0.22 Gt). The balanced emission increase between the demand categories is not in line with Dwivedi & Soni's results indicating that increased household consumption (+0.79 Gt CO_2) was by far the largest contributor to CO_2 emission growth in the period 2000-2016[45]. It is likely that this is due to differences in data.

India's GDP is found to have increased from 678 billion \$US15 in 1995 to 1275 billion \$US15 in 2005 and 2466 billion \$US15 in 2015. Applying the numbers from Figure 14, this results in emission multipliers (in kg CO_2e per \$US15) of 2.22, 1.53, and 1.22, respectively. Hence, 1.53 is the 2005 emission multiplier that will be used as a reference in evaluating pledge 4. In order to fulfill the pledge, the 2030 emission multiplier will have to be 0.84. In other words, applying the estimated 2030 GDP of 4959 billion \$US15, the emissions will have to be 4.17 Gt CO_2e or less in order to achieve an emission multiplier decrease in excess of 45%. The 2015 value of 1.22 indicates that the development is moving in the right direction as the emission multiplier already had decreased by 20.5% during the 2005-2015 period. This is in line with the results of India's third Biennial Update Report stating that the emission intensity of GDP dropped by 24% from 2005 to 2016[34]. It is also close to the relative change between 2005 and 2015 found in Figure 3 (Our World In Data[1] [2]) of -17.5%.

While the overall emissions numbers are practically equal to the ones found in Figure 1 (Our World In Data[1]), the calculated GDPs are consistently higher than the ones found in Figure 2 (Our World In Data[2]) (1995: 596 billion $US15, 2005: 1094 billion $US15, 2015: 2104 billion $US15). As a result, the emission multipliers are consistently smaller than the ones presented in Figure 3 (Our World In Data[1] [2]). Subsequently, pledge 4 would have been easier to fulfill if the 2005 emission multiplier found in Figure 3 (1.77) had been used as a reference instead of the one found in the calculations of this thesis (1.53). However, as the entire study builds on the outcome of manipulated MRIO tables, the latter will be used.

The emission multiplier of India's exports developed in a similar manner as the overall emission multiplier. It decreased from 2.04 in 1995 to 1.51 in 2005 and 1.12 in 2015. The 2015-value being lower than the overall 2015-emission multiplier indicates that increasing export volumes contribute towards lowering India's emissions per GDP. This naturally also means that the emission multiplier of India's domestic demand volumes is higher than the overall emission multiplier. Hence, it appears that increasing the export share of India's demand volumes can a have positive impact on the fulfillment of pledge 4.

The SDA of the emission development throughout the 1995-2015 period is presented in Figure 15. The results are summarized in Table 4. Increased demand volume (y) is identified as the main driver of emissions in both 10-year periods (1995-2005: +1182 Mt CO_2e, 2005-2015: +1841 Mt CO_2e). Figure B1 in the appendix shows the sectors with the most significant contributions to the emission changes during the period. The figure shows that the large y-deltas were mainly due to increased 'electricity by coal' demands. It is noted that there were no sectors experiencing

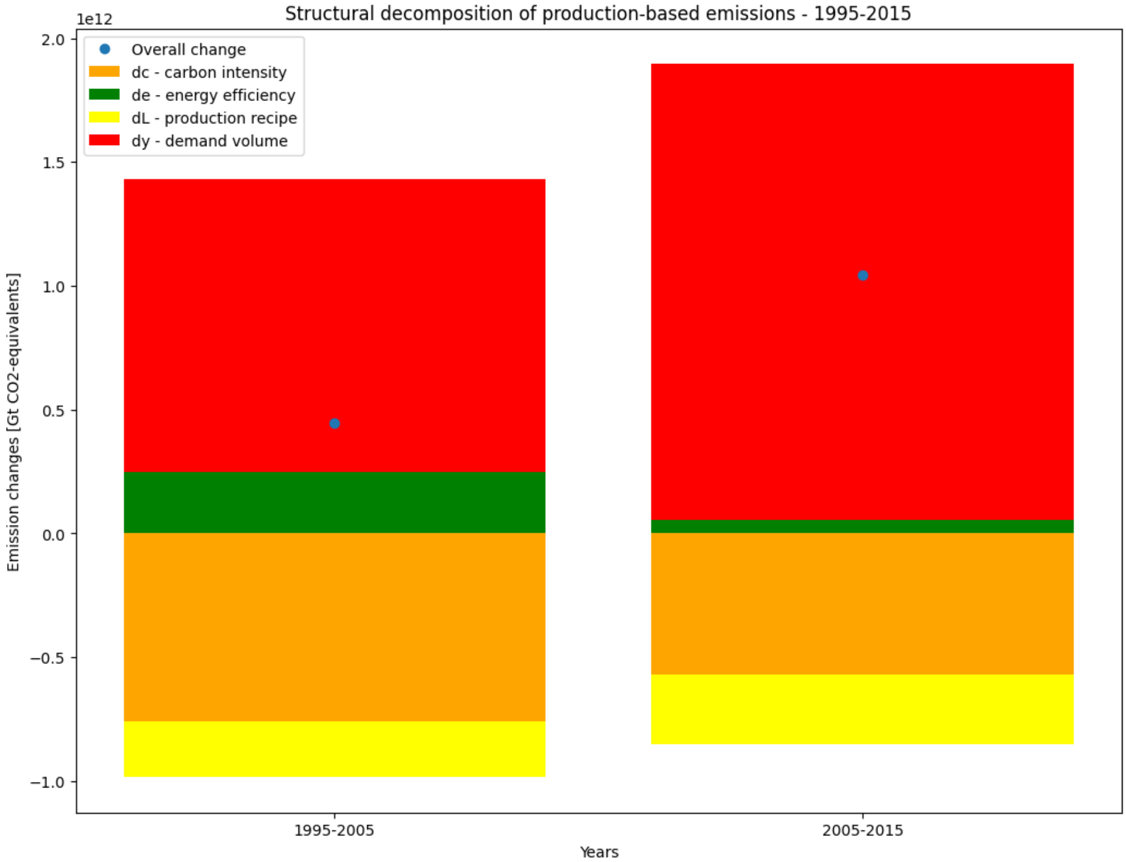


Figure 15: SDA of production-based emissions, 1995-2015 [Gt CO_2e]

Table 4: Drivers of changes in production-based emissions, 1995-2015 [Mt CO_2e]

Driving factor	Changes, 1995 - 2005	Changes, 2005 - 2015
Carbon intensity	-757	-571
Energy efficiency	+247	+54
Production recipe	-225	-278
Demand volume	+1182	+1841
Sum	**+447**	**+1046**

significantly decreasing demand volumes between 1995 and 2015. This illustrates India's stable economic growth during the period. 'Cattle' and 'paddy rice' are identified as the second and third largest contributors to the y-deltas. They were also the most significant positive contributors to the production recipe (**L**) deltas. However, they were far from large enough to hinder the overall **L**-deltas from becoming negative (1995-2005: -225 Mt CO_2e, 2005-2015: -278 Mt CO_2e), which was mainly due to the substantial negative contributions of the 'electricity by coal' sector.

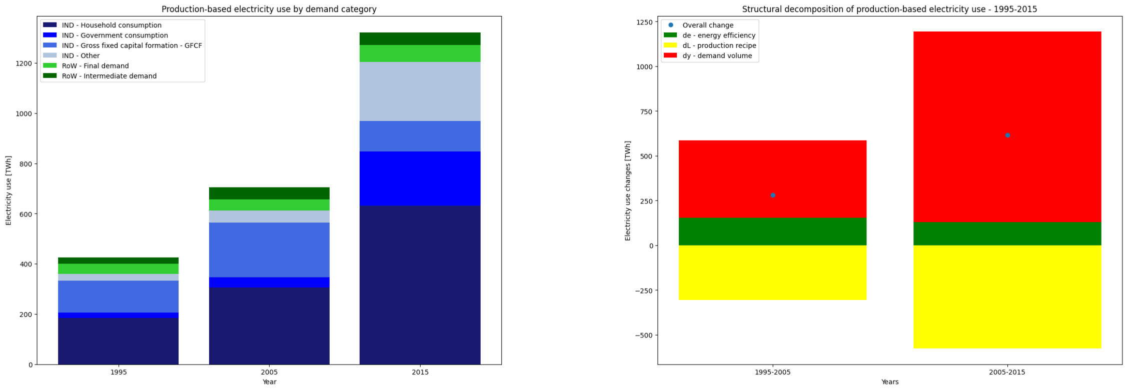
The deltas of 'carbon intensity' (i.e., emissions per unit energy use) (1995-2005: -757 Mt CO_2e, 2005-2015: -571 Mt CO_2e) and 'energy efficiency' (i.e., energy use per unit output of the economy) (1995-2005: +247 Mt CO_2e, 2005-2015: +54 Mt CO_2e) must be interpreted in light of each other. Their sum constitutes the change in 'carbon efficiency' (i.e., emissions per unit output of the economy), which steadily developed in the right direction during the 20-year period (1995-2005: -510 Mt CO_2e, 2005-2015: -517 Mt CO_2e). Figure B1 in the appendix shows that many sectors experienced contradictory developments within 'carbon intensity' (c) and 'energy efficiency' (e). As an example, the 2005-2015 'vegetables, fruits, nuts' sector's c- and e- deltas were -420 Mt and +411 Mt, respectively. Despite the enormous individual deltas, the sector's overall emission change was only +19 Mt. Similar decomposition results are seen for sectors like 'paddy rice', 'oil seeds', 'raw milk', and various waste treatment services. This illustrates an important feature of SDA-methodology: the different decomposition factors may contain huge individual deltas, but the overall change within a sector can still be small. There are nevertheless sectors whose c- and e- deltas were coinciding. Among them is the 'cattle' sector, who experienced significant improvements in both carbon intensity and energy efficiency during the 20-year period. At the other end of the scale, the 'electricity by coal' sector became both more carbon-intensive and less energy efficient, which contributed to the sector being the by far largest contributor to the overall emission increases in both 10-year periods. 'Other bituminous coal' being the sector with the second largest overall emission increase highlights India's increased coal-dependency. 'Cement, lime and plaster' followed on third place, while 'cattle' was the main negative contributor.

The identified y-deltas are significantly larger than those presented in the SDA literature review (Zhu et al.: +510 Mt CO_2 (2007/08-2013/14), Wang et al.: +981 Mt CO_2 (2000-2014), Dwivedi & Soni: +1901 Mt CO_2 (2000-2016), Malik & Lan: +1.8 Gt CO_2 (excl. exports, 1990-2010))[38] [43] [44] [45]. However, as discussed in the literature review section, none of the papers include other GHGs than CO_2, which indisputably influences the results. Differences in SDA methodology and time frames also naturally affects the magnitude of the calculated deltas, causing large differences among the reviewed studies as well. This is highlighted by the dissimilar production recipe deltas (Zhu et al.: +286 Mt CO_2 (2007/08-2013/14), Wang et al.: -249 Mt CO_2 (2000-2014), Dwivedi & Soni: -216 Mt CO_2 (2000-2016), Malik & Lan: +0.3 Gt CO_2 (excl. exports, 1990-2010)). There are also different views on carbon efficiency's effect on the emissions during the last decades (Zhu et al.: -81 Mt CO_2 (2007/08-2013/14), Wang et al.: +146 Mt CO_2 (2000-2014), Dwivedi & Soni: -388 Mt CO_2 (2000-2016), Malik & Lan: -1.3 Gt CO_2 (excl. exports, 1990-2010)). Being the only study splitting carbon efficiency into carbon intensity and energy efficiency, Wang et al.'s results regarding the former having a negative delta (-50 Mt CO_2) and the latter having a positive delta (+196 Mt CO_2) agree with the findings of this thesis.

The emissions from the power sector increased from 315 Mt in 1995 to 498 Mt in 2005 and 923 Mt in 2015, equivalent to total emission shares of 21%, 26%, and 31%, respectively. Compared to Figure 8 (Our World In Data[1] [10]), the emission numbers are consistently about 14-18% smaller. On the other hand, the total electricity generation outputs in EXIOBASE are consistently much larger than those seen in Figure 9 (Our World In Data/Ember[11] [15]) for the 1995-2015 period.

On average, they are about 1.77 times larger. To be able to directly compare the electricity mixes, they are scaled down when extracted from EXIOBASE by dividing by an adjustment factor, $en_{fac} = 1.77$. Naturally, en_{fac} is also applied to the numbers entered into EXIOBASE in the 2030 scenarios.

The extracted production-based electricity use by demand category is presented in Figure 16a. It shows that all demand categories - except GFCF - required increased inputs of electricity in the course of the 1995-2015 period. GFCF's demand increased between 1995 and 2005, before it dropped to below 1995 levels in 2015. The reason is not clear. Like for the emission development, household consumption had the largest absolute increase in electricity use during the period.



(a) By demand category

(b) SDA

Figure 16: Production-based electricity use, 1995-2015 [TWh]

Figure 16b presents the SDA of the electricity use changes. Figure C1 in the appendix shows that all decomposition category deltas were predominantly driven by changes in the 'electricity by coal' sector. In other words, the overall increase in electricity use was almost entirely a result of the increased demand volume, decreased energy efficiency, and the negative **L**-delta of the 'electricity by coal' sector. The large negative **L**-deltas ensured that the emissions per generated TWh decreased by 5.3% in the course of the 20-year period, which is similar to the findings of the literature review. The non-positive **L**-deltas are in line with Garg & Shukla's finding of the positive effects of India switching to less carbon-intensive fuels [13]. The positive e-deltas are however not in line with Chikkatur et al.'s claim regarding India's coal-fired power becoming more efficient [12].

The extracted electricity mixes of 1995, 2005, and 2015 are presented in Table 5. The table shows a persistent coal-dominated electricity mix, which is in line with the findings of the literature review. However, compared to Figure 9 (Our World In Data/Ember [11] [15]), coal's shares are slightly too large, diminishing the renewable power development. Especially hydro power's shares are significantly undersized throughout the entire 20-year period. The shares of biomass & waste

Table 5: Electricity mix, 1995-2015 [TWh]

Power generation technology	1995	2005	2015
Coal	351	595	1176
Gas	27	50	52
Petroleum	19	13	6
Nuclear	12	23	52
Solar	2	0	1
Wind	3	2	8
Hydro	10	21	26
Biomass & waste	0	0	0
Sum	**427**	**705**	**1322**
Renewable el. requirements	**3%**	**3%**	**3%**

and wind are also undersized, especially in the 2015-electricity mix. According to the results, the renewable electricity share remained stable at 3% throughout the 20-year period. Figure 9 tells another story, with renewable shares of 18% in 1995 and 15% in 2005 and 2015. The large differences are mainly due to hydro power's undersized shares in Table 5.

In summary, none of the emission SDA results of this thesis are considered conflicting with the findings of the studies reviewed in section 2. The overall emission development is also completely in line with Figure 1 (Our World In Data [1]). The extracted electricity mixes are on the other hand slightly different from the ones found in external sources. This will have an impact on the 2030 BAU scenario, but not the other scenarios as they will implement individually constructed electricity mixes. Both the SDAs show stable trends for all decomposition factors, which bodes well for using the development between 1995 and 2015 as a basis in forecasting future emissions and electricity use. In conclusion, the results found in this section are considered satisfactory to be used as inputs in projecting 2030 MRIO tables.

5 Results & Discussion

The main findings of this thesis are summarized in Table 6. The color-coded table also indicates the likelihood of each scenario and pledge. Dark red indicates that the pledge is far off being fulfilled or that scenarios are highly unlikely. Neon green indicates that the pledge is by far fulfilled or that scenarios are highly likely. Lighter shades of the colors indicate values closer to mid-range levels.

In summary, the CEA scenario (non-fossil fuel electricity capacity: 520 GW, emission multiplier change: -40%) and CEA45%a scenario (non-fossil fuel electricity capacity: 479 GW, emission multiplier change: -45%) being identified as likely scenarios indicate that pledge 1 (500 GW of non-fossil fuel electricity capacity) is possible to fulfill and pledge 4 (45% decrease in emission multiplier compared to 2005 levels) is likely to be fulfilled. The unlikely PG scenario being the only one that fulfills pledge 2 (50% of electricity requirements from renewable sources) indicates that this pledge is highly unlikely to be fulfilled.

The magnitude of solar and wind power capacity additions is identified as a key factor affecting the fulfillment of all three pledges. Pledge 2 and pledge 4 also heavily rely on the development within the coal-fired power sector. Additionally, the magnitude of emission savings from carbon efficiency measures - predominantly within the industrial sector and power sector - is identified as a cornerstone affecting the fulfillment of pledge 4. The key factors - as well as the details of Table 6 - will be elaborated upon throughout this section.

Table 6: Summary of main results

Scenario	**Pledge 1** Target: 500 GW	**Pledge 2** Target: 50%	**Pledge 4** Target: -45%	Scenario likelihood
BAU	**51 GW**	**2%**	**-29%**	**Highly unlikely**
CEA	**520 GW**	**36%**	**-40%**	**Likely**
PG	**654 GW**	**50%**	**-44%**	**Unlikely**
CEA45%a	**479 GW**	**36%**	**-45%**	**Likely**
CEA45%b	**285 GW**	**30%**	**-45%**	**Unlikely**
Pledge likelihood	**Possible**	**Highly unlikely**	**Likely**	

BAU (Business-as-Usual): entirely based on historical trends.
CEA (Central Electricity Authority): BAU scenario + the CEA's altered power capacity projections.
PG (Power sector Goals): BAU scenario + power capacities/electricity mix designed to fulfill pledges 1 & 2.
CEA45%a: CEA scenario + share-wise equal carbon efficiency improvements within all sectors.
CEA45%b: CEA scenario + carbon efficiency improvements based on the SDA results of the CEA scenario.

5.1 Power sector projections

The 2030 power capacity and electricity mix projections by scenario are presented in Table 7 and Table 8, respectively. The last rows of the tables are color coded to imply the status of fulfilling pledge 1 (500 GW of non-fossil fuel electricity capacity) and pledge 2 (50% of electricity requirements from renewable sources), respectively. As will be discussed in detail, fulfilling pledge 1 is considered possible, while fulfilling pledge 2 seems highly unlikely. The scenarios' capacity and generation shares of different power generation technologies are presented in Figure D1 and Figure E1 in the appendix.

The extracted BAU en_{fac}-adjusted total electricity requirements of 2917 TWh is 1.159 times larger than the CEA's projected 2518 TWh. As the latter is used as a benchmark, the BAU energy efficiency factors found in Table 3 are set to 1.159 for every power generation technology. As expected, the scenario's electricity mix is heavily dominated by coal, which makes up 92% of the total electricity requirements. This is due to the scenario being solely based on the development in the period 1995-2015 when the coal power requirements steadily increased from 82% to 89% according to Table 5. The corresponding installed coal power capacity of 511 GW is in excess of two times larger than the current. Obtaining such a capacity seems highly unlikely as the

Table 7: Installed power capacity projections by scenario [GW]

Power generation technology	BAU	CEA	PG	CEA45%a	CEA45%b
Coal	511	228*	180	210	242
Gas	12	25	24	23	4
Petroleum	4	5**	5	5	2
Nuclear	25	19	9	17	21
Solar	1	280	320	258	125
Wind	8	140	180	129	63
Hydro	16	61	95	56	50
Biomass & waste	1	20**	50	18	26
Sum	**579**	**778**	**862**	**716**	**533**
Non-fossil fuel power capacity	**51**	**520**	**654**	**479**	**285**

* *Originally 267 GW, lowered to achieve 2518 TWh in total electricity generation.*

** *Other = Petroleum + Biomass & waste = 25 GW. Shares estimated based on other data*[3] [11] [17].

Table 8: Electricity mix by scenario [TWh]

Power generation technology	BAU	CEA	PG	CEA45%a	CEA45%b
Coal	2678	1383*	1092	1326	1423
Gas	46	114	107	109	46
Petroleum	6	8	8	8	5
Nuclear	130	113	52	109	119
Solar	2	411	470	394	275
Wind	11	208	268	200	139
Hydro	44	196	305	188	177
Biomass & waste	2	86	215	83	98
Sum	**2917**	**2518**	**2518**	**2416**	**2283**
Renewable el. requirements	**2%**	**36%**	**50%**	**36%**	**30%**

* *Originally 1620 TWh, lowered to achieve 2518 TWh in total electricity generation.*

growth in new installations of coal-fired power has stagnated the last couple of years. The net added capacity between 2016 and 2021 was only 24 GW, after 110 GW was added between 2010 and 2016[15]. In addition, the literature review revealed that the 2030 coal power capacity is likely to be in the range of 160-319 GW, well below the BAU projection. As the scenario is built on data from 2015 and earlier, it also fails to pick up the explosive development in solar and wind power. The respective 2030 BAU capacities of 1 GW and 8 GW are way below the corresponding 2021 capacities of 50 GW and 40 GW. The projected capacities of gas, petroleum, hydro and biomass & waste are also smaller than their respective 2021 capacities. The coal-dominated electricity mix results in the cumulative non-fossil fuel power capacity of 51 GW and the renewable electricity requirements of 2% both being way off their target values. However, as the scenario seems highly unlikely, these results will not be given much attention. The remaining scenarios are directly or indirectly built on the BAU scenario but implement different electricity mixes, all considered more likely. The BAU scenario can thus be considered a reference scenario rather than a viable option.

All four remaining scenarios' coal power capacity projections are within the literature review's range of 160-319 GW. The CEA scenario's original 267 GW was lowered to 228 GW to meet the total electricity requirements of 2518 TWh. In other words, the altered CEA electricity mix assumes a total installed coal power capacity equaling 2021 levels. This assumption is in line with the CEA's recommendation of not retiring any coal-fired power plants until 2030[16]. It also balances the conflicting signals from the Indian government concerning coal's role in the future electricity mix. In 2022, they announced that the electricity output of at least 81 coal-fired power plants would be reduced by 2026[16]. Later that same year, Indian Power Minister Raj Kumar Singh said that they were preparing to add up to 56 GW of coal-fired generation capacity by 2030[57]. In other words, there is a great deal of uncertainty related to the projected 2030 coal power capacity. As will be discussed later on, it will be heavily influenced by the ratio of new, more efficient power generation technology replacing outdated power plants. Regardless, considering the original CEA electricity mix was presented in 2020 - prior to the COP26 coal phase down deal - lowering the projected coal power capacity rather than the other power generation technologies' capacities seems the most feasible solution to obtain the total electricity requirements of 2518 TWh. The reduction in overall installed power capacity is needed due to Figure 13 (Our World In Data/Ember [11] [15])) presenting larger 'average generation per capacity'-factors than those applied by the CEA. However, as visualized in Figure 12, there are very large fluctuations in these factors, and hence, it is impossible to obtain "correct" values. Without lowering coal's capacity, the total electricity requirements would be 2755 TWh, decreasing the renewable generation share from 36% to 33%. The latter is equal to the share projected by Dasgupta & Sarangi [20]. It is however noted that the share is significantly smaller than the 40% projected in the CEA report [5]. In other words, the CEA assumes higher renewable power generation technology efficiencies and/or lower fossil fuel power generation technology efficiencies. Naturally, the reduction in installed capacity does not affect the total non-fossil fuel power capacity of 520 GW. These results confirm the expectations presented in the literature review section concerning the CEA's projections resulting in pledge 1 being fulfilled and pledge 2 not being fulfilled.

Both pledges are of course fulfilled in the scenario specifically designed to achieve the power sector objectives, the PG scenario. Table 7 and Table 8 clearly illustrate that pledge 2 is the constraining factor in fulfilling both pledges simultaneously as the PG scenario is the only scenario that obtains the 50% renewable share. Obtaining such an electricity mix requires significant extra installed capacity for all the renewable generation technologies but also a reduction in coal power capacity to well below current levels. Of course, an alternative is maintaining the current coal capacity and reducing the outputs of the power plants, as proposed in the Indian government's announcement mentioned above. Regardless, the electricity requirements from coal-fired power must decrease or at least be stabilized in order for there to be any possibility of fulfilling pledge 2. Note that also the nuclear and gas power capacities are kept on current levels due to them not being renewable sources of energy. Petroleum's capacity is set to the same value as the CEA scenario's, which is well below current levels. The cumulative increase in renewable power capacity compared to the CEA scenario is 134 GW, a quite significant amount. The extra increase is distributed evenly between the renewable sources. In Das et al.'s study from January 2023 - referred to in the literature review section - a table of upper bounds on 2030 capacity potentials is presented [36]. The potentials are compiled based on various sources and expert judgement. The upper bound on solar power is estimated to be 280 GW, while the combined onshore and offshore wind capacity limit is 160 GW. Hydro power's upper bound is estimated to be 64 GW. In other words, the PG scenario must be considered unlikely, and even the CEA scenario is on the verge of infeasibility. However, the power capacity projections presented in Das et al.'s study are approximately the same as the CEA scenario's, barring coal's higher installed capacity (319 GW). Hence, using Das et al.'s projections as reference, the CEA scenario must be considered likely.

As the BAU scenario is considered highly unlikely and the PG scenario is considered unlikely, the two remaining scenarios build on the CEA scenario. They are both specifically designed solely to fulfill pledge 4, without focusing on the power sector objectives. As will be further elaborated upon in subsection 5.2, an overall increase in carbon efficiency of about 8% will be needed in order to fulfill pledge 4 using the CEA scenario as a basis. The CEA45%a scenario assumes that efficiency measures are distributed equally between 'carbon intensity' and 'energy efficiency' and equally between all 200 sectors. In other words, an increase of 4% in energy efficiency in all sectors is needed. Subsequently, Table 3 shows energy efficiency factors of $1 - 0.04 = 0.96$ for all power generation technologies. This results in a share-wise equal electricity mix to that of the CEA scenario but with a decreased overall output of 102 TWh. The renewable electricity requirements share remains at 36%, subsequently not fulfilling pledge 2. Due to the energy efficiency improvements, the installed power capacity projections are about 8% smaller for all technologies. Subsequently, the cumulative non-fossil power capacity of 479 GW is not sufficient to fulfill pledge 1. It must however be noted that although the pledge on paper is not fulfilled, the purpose of the pledge is. The share-wise non-fossil power capacity is still the same as for the pledge 1-fulfilling CEA scenario, and the electricity requirements needed to drive the economy are satisfied. As the power sector pledges indirectly can be considered emission abatement pledges, the CEA45%a scenario must be considered an enhanced version of the CEA scenario, regardless of whether the pledges are fulfilled or not.

The CEA45%b scenario assumes that the carbon efficiency measures are distributed between 'carbon intensity' and 'energy efficiency' - and between the 200 sectors - based on the SDA results of the CEA scenario. In other words, the efficiency trends within each sector of the CEA scenario are enhanced to fulfill pledge 4. Table 3 shows that there are large variations within the power generation technology sectors' energy efficiency factors. Coal, nuclear and biomass & waste are projected to have negative developments based on the SDA of the CEA scenario and are thus assigned factors above 1. Hydro is projected to have a noteworthy positive development, while the remaining technologies all have extreme improvements. Subsequently, the overall energy efficiency improvement within the electricity sector of 9.3% is significantly larger than the one of the CEA45%a scenario. In other words, the energy efficiency development of the power sector is projected to be notably better than the average improvement of India's economy according to the results of the CEA scenario. This also enhances the feasibility of the CEA45%a scenario, as an overall increase in energy efficiency of 4% appears more achievable than 9.3%. The development between 2005 and 2015 can be used as a reference. Figure 9 (Our World In Data/Ember [11] [15]) shows that the main electricity sources in the 10-year period were coal, hydro and gas. Their respective energy efficiency change factors were 1.158, 0.746 and 0.625, meaning hydro and gas had significantly larger changes in a positive direction than coal's negative change. However, Figure 16(b) and Figure C1(d) in the appendix show that the overall energy efficiency moved in the wrong direction due to coal's larger power generation share. Yet again, this illustrates coal-fired power's enormous influence on India's economy. Managing the coal sector will thus be key in achieving energy efficiency improvements substantial enough to fulfill pledge 4. As discussed in section 4, Chikkatur et al. and Garg & Shukla's studies agree on India's coal combustion power plants becoming more efficient, while the results of this thesis suggest otherwise. Figure 12 (Our World In Data/Ember [11] [15]) showing coal's development of generated TWh per GW installed capacity is in line with the results of this thesis. It shows a 2005-value of 6.8 TWh/GW and a 2015-value of 5.3 TWh/GW. However, the trend is positive, with a 2021-value of 5.5 TWh/GW. It is however the value presented in Figure 13 (Our World In Data/Ember [11] [15]) of 6.1 TWh/GW that is used in the CEA scenario projections, and hence, obtaining a 2030 value above this will be key. Dividing coal power's output in Table 8 with the respective power capacity in Table 7 results in the CEA45%b scenario assuming 5.9 TWh/GW. The CEA45%a scenario assumes 6.3 TWh/GW. It must however be noted that if the Indian government's plans of reducing the electricity outputs of coal-fired power plants are acted upon, the energy efficiency factors are of less importance. Coal phase down must be considered a positive measure regardless of whether values above current levels are obtained or not.

While coal's development presented in Figure 12 (Our World In Data/Ember [11] [15]) is in line with the results of Figure C1(d) in the appendix, hydro and gas' are not. Figure 12 shows a stable hydro power development with equal 2005- and 2015-values. Gas had a quite drastic drop between 2011 and 2014, resulting in significantly different 2005- and 2015-values. As discussed above, variations in electricity outputs occur due to a number of reasons, not only efficiency measures. Hence, directly comparing and combining energy efficiency factors and values of generated TWh per GW installed capacity cannot be considered an ideal approach. Nevertheless, it should give an indication of the magnitude of the measures required to fulfill the pledges.

While the CEA45%b scenario's coal energy efficiency factor might by more in line with the development in the last decades, the majority of the remaining power generation technologies' efficiency factors are more reasonable in the CEA45%a scenario. A 4% increase in energy efficiency seems more realistic than the 33.1% increase projected for solar and wind power in the CEA45%b scenario. The huge improvement would result in output values of 2.2 TWh/GW for both power generation technologies, 0.7 TWh/GW above the ones used in the CEA scenario. According to Figure 12 (Our World In Data/Ember [11] [15])), such outputs have not been observed in the course of the last decades. Solar came close in 2012/13, but it is likely that the large values were due to the low cumulative installed capacities of less than 2 GW. Hence, using the values after 2015 (1.2-1.5 TWh/GW) should result in a better representation of the outputs that can be expected in the future. Wind has a relatively stable trend, especially after 2005, and future values in the range of 1.3-1.7 TWh/GW can be expected. Reaching 2.2 TWh/GW seems highly unlikely for both power generation technologies. Hence, the CEA45%a scenario is considered to be significantly more likely than the CEA45%b scenario.

The projected electricity mixes of three papers reviewed in section 2 are considered fitted to be directly compared to the scenarios of this thesis: Das et al.'s, Dasgupta & Sarangi's and the CEA report's [5] [20] [36]. Bakir et al.'s study could also have been included, but it is chosen not to as their results build on regression-generated values found using a linear approach, which is not appropriate according to the other studies. There are large variations in the forecast 2030 total electricity requirements among the three papers. Dasgupta & Sarangi project 2352 TWh, the CEA report project 2518 TWh and Das et al. project 3404 TWh. Das et al.'s much larger number is due to the projected installed coal power capacity of 319 GW, which is much larger than those of the two other papers (Dasgupta & Sarangi: 200 GW, CEA report: 267 GW). This results in large variations in the reported absolute cumulative non-fossil power capacities. However, there are small variations in the relative cumulative non-fossil power capacities. Das et al. found a total non-fossil power capacity share of 59% due to an installed capacity of 510 GW, Dasgupta & Sarangi found a share of 63% due to an installed capacity of 357 GW, while the CEA report found a share of 64% due to an installed capacity of 520 GW. Despite similar projected non-fossil power capacity shares, the renewable electricity shares differ. Das et al. project 30%, Dasgupta & Sarangi 33%, and the CEA report 40%. As nuclear power's projections are quite similar for all three papers, this is due to variations in applied 'generation per capacity'-values. This highlights the outcome of the above discussion concerning the uncertainty related to these values. Nevertheless, the collective basis of the numbers extracted from the three papers supports the claim that the CEA scenario and the two scenarios using it as a basis are the most feasible out of the five presented in this study. Hence, these will be the focus of the remaining discussion.

Figure 17 presents the projected 2030 electricity use by demand category by scenario. 2015-values are added to the figure to serve as a reference. The figure shows that household consumption is expected to remain the dominating demand category. Regardless of scenario, households will consume almost half of the total electricity requirements, thus having the largest potential of energy efficiency gains. Vishwanathan et al.'s report reviewed in section 2 points out that increased levels of income and rapid urbanization has increased the penetration of electric appliances like refrigerators, washing machines, fans, and air conditioners [22]. Measures should focus on improving the efficiency of these appliances [22]. In addition, a shift to LEDs by phasing out incandescent lights is considered a high impact opportunity also relevant for the residential sector [22]. Vishwanathan et al.'s report also discusses India's high transmission and distribution losses. However, the presented loss values are consistently lower than the CEA's official numbers [58]. According to the CEA, the losses steadily decreased from approximately 30% in 2005 to 23% in 2015 [58]. The positive trend has continued, and provisional numbers show that the losses were less than 21% in 2019 [58]. As there still is large room for improvement until the global average of 9% is reached, minimizing the difference between generated and distributed power is considered another high impact opportunity [22]. Measures include converting low voltage lines to high voltage lines, reducing the number of transformation steps, and replacing old cables [58]. As will be elaborated upon in subsection 5.2, generation losses can be reduced by implementing supercritical and ultra-supercritical coal-fired power plants with increased technical efficiencies compared to the majority of the current coal power capacity [22].

Vishwanathan et al. also highlight how electricity is considered to be more efficient than other types of energy carriers [22]. Hence, electrification can be considered an energy efficiency measure. Large-scale construction of solar and wind power plants will thus not only contribute to a less carbon-intensive electricity mix but also lead to energy savings. The SDAs of projected electricity use by scenario presented in Figure 18 and summarized in Table 9 are dominated by these two power generation technologies, in addition to coal and hydro power. However, the accuracy of the SDAs is questionable due to differences in the 2015 electricity mixes of external sources and the one presented in Table 5. As discussed in section 4, hydro power's share is significantly undersized in Table 5, leading to it being portrayed to have a more explosive development in the SDAs than it actually is projected to. On the other hand, coal power's share is oversized, resulting in it being portrayed to have a less substantial development than it actually is projected to. Keeping this in mind, Figure I1, Figure M1 and Figure O1 in the appendix still show that the 'electricity by coal' sector will by far be the largest contributor (+757 TWh) to the demand volume changes projected for the three scenarios considered (+1463 TWh overall). Solar (+229 TWh) and wind (+164 TWh) follow on second and third place. The figures also show that the 'electricity by coal' sector's production recipe delta is substantially negative (-653 TWh). However, the overall

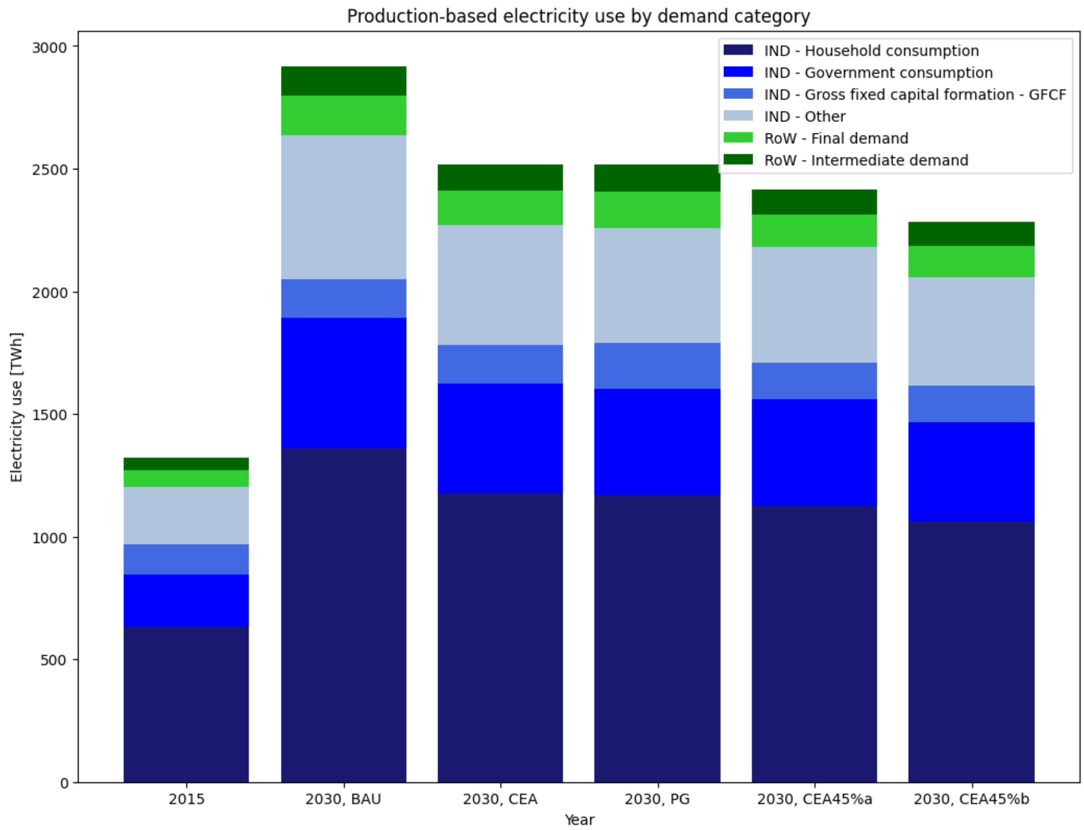


Figure 17: Projected production-based electricity use, 2015-2030 [TWh]

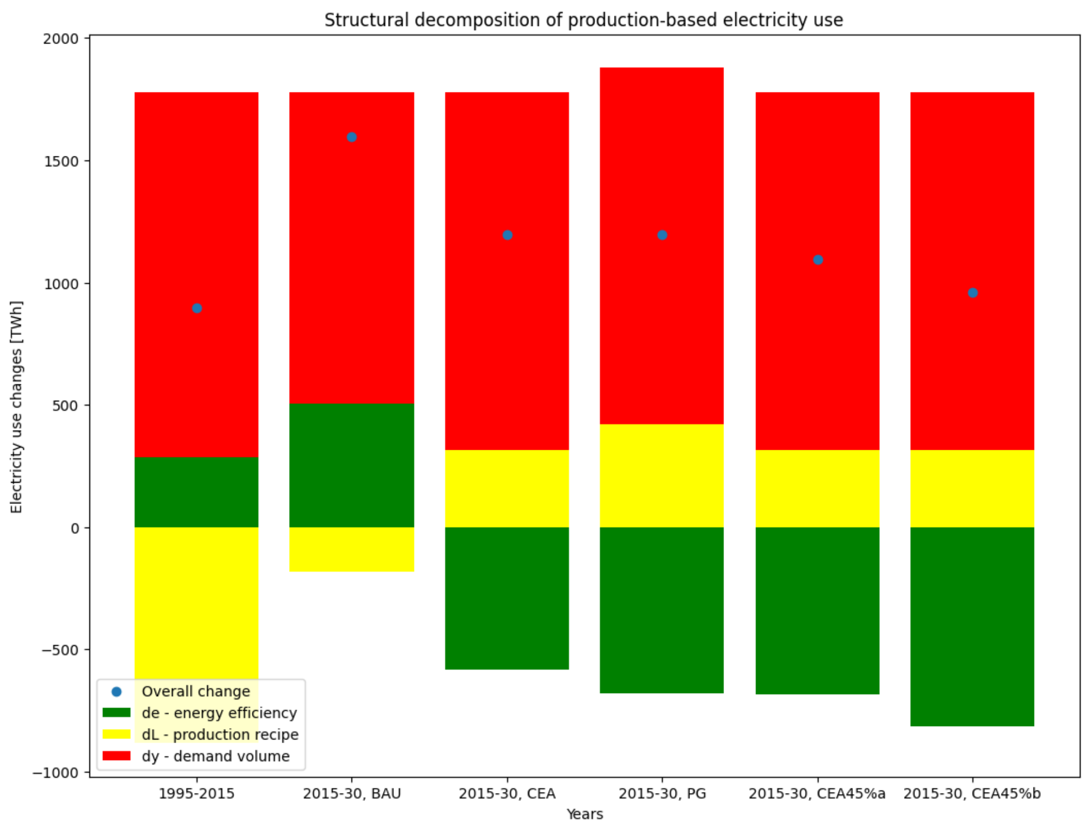


Figure 18: SDA of projected production-based electricity use, 2015-2030 [TWh]

Table 9: Drivers of changes in production-based electricity use, 2015-2030 [TWh]

Driving factor	**BAU**	**CEA**	**PG**	**CEA45%a**	**CEA45%b**
Energy efficiency	+504	-582	-681	-684	-817
Production recipe	-181	+316	+422	+316	+316
Demand volume	+1272	+1463	+1455	+1463	+1463
Sum	**+1595**	**+1196**	**+1196**	**+1094**	**+961**

L-delta is positive (+316 TWh), which is mainly due to solar (+518 TWh) and wind (+208 TWh). The projected development can be interpreted as solar and wind power meeting the intersectoral demand previously met by coal-fired power. Note that the three scenarios' y- and **L**-deltas are identical due to the CEA45%a- and b-scenario only assuming changes in energy efficiency compared to the CEA scenario. Due to the electricity mix of the CEA scenario being used as a basis for the CEA45% scenarios, the differences of the scenarios' e-deltas are direct results of their applied energy efficiency factors presented in Table 3. As the CEA scenario's coal e-delta (+102 TWh) is positive, so are the CEA45%a- (+46 TWh) and b-scenarios' (+143 TWh). The same goes for the remaining power generation technologies. The respective solar e-deltas of -337 TWh, -354 TWh and -473 TWh and wind e-deltas of -171 TWh, -179 TWh and -240 TWh are the main contributors to the projected overall negative energy efficiency changes.

When adding the individual decomposition factor deltas, the sums naturally equal the differences between the scenarios' electricity mixes presented in Table 8 and the 2015-electricity mix presented in Table 5. Keeping in mind the inaccuracies of the latter, the results highlight the large-scale capacity additions of solar and wind power needed in order to obtain such electricity mixes. Figure 19 shows the development in India's cumulative installed capacities of the two power generation technologies [15]. It also shows the addition developments needed in order to obtain the CEA scenarios' capacity projections assuming linear expansions. To reach 280 GW, approximately 27 GW of solar power will have to be installed annually between 2023 and 2030. As reference, 10 GW was added in 2021 and 14 GW was added in 2022 [15]. To reach 140 GW cumulative wind power capacity, approximately 12 GW must be added annually. As reference, 2 GW was added in both 2021 and 2022 [15]. If the annually added solar and wind power capacities remain at current levels, India will be far off reaching its power sector targets. Neither of the power generation technologies are currently near their target values of average annually added capacities. However, the assumption of linear developments is not necessarily the most realistic approach. Exponential growth might be

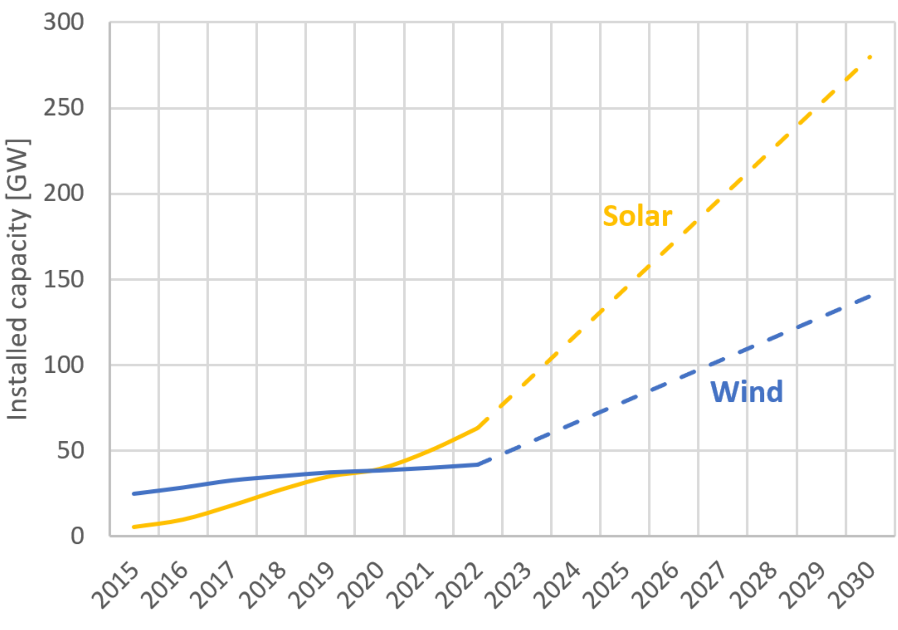


Figure 19: Solar and wind power capacities [GW]

a more pragmatic assumption. As an example, China had a rather modest installed wind power capacity at the start of the 21st century. Then, between 2008 and 2015, the cumulative capacity rapidly increased from 8 GW to 131 GW [15]. A similar development was seen in the country's solar power sector. Between 2012 and 2019 the cumulative capacity increased from 7 GW to 205 GW [15]. In 2022, China's wind and solar power capacities were 366 GW and 393 GW, respectively [15]. If India can copy the development seen in its neighboring country its power sector targets will be within reach.

There is no doubt that it will be challenging to obtain the CEA scenario's electricity mix. However, as per draft of the CEA's National Electricity Plan published in September 2022, it is believed to be achievable [59]. According to the report, 132 GW of solar power capacity and 41 GW of wind power capacity are estimated to be installed by 2027. The resulting 2027 solar and wind cumulative power capacities are 195 GW and 83 GW, respectively [15] [59]. The numbers are equivalent to more than three times the current solar power capacity, and two times the current wind power capacity. The report also projects the absolute installation additions of solar and wind power to surpass those of the 2022-2027 period in the subsequent five-year period (2027-2032). Hence, despite both generation technologies not keeping up with the 2027 values found in Figure 19, the growth after 2027 might be large enough for them to reach their 2030 target values. The trend is positive, as India's investments in renewable energy reached a record $US14.5 billion in financial year 2021-22 [60]. However, the Institute for Energy Economics and Financial Analysis (IEEFA) has stated that the investments in coming years would have to be $US30-$US40 billion annually for India to surpass 450 GW of renewable power capacity by 2030 [60]. At the same time, due to rapidly decreasing costs, solar and wind power have become the cheapest electricity sources in India, even without subsidies [4]. Hence, factoring in the opportunity costs and India's overall expected significant increase in GDP, reaching the necessary investment levels should be achievable.

Figure 19 shows that the additions in wind power capacity have stagnated the last couple of years. Undoubtedly, this is in part a result of the COVID-19 pandemic. Just in excess of 4 GW of new capacity was installed in the period 2019-2022. However, in the same period, 28 GW of solar capacity was added. The relative developments can be interpreted as solar power currently being preferred to wind power. Solar power is considered a slightly cheaper electricity source than wind power [4]. A 2030 scenario in which 280 GW of solar power is reached or even surpassed, while 140 GW of wind power is not, is a possible outcome of the current development. As presented in Figure 12 (Our World In Data/Ember [11] [15]) and Figure 13 (Our World In Data/Ember [11] [15]), there is not a great difference in the efficiencies of the two power generation technologies. However, as solar power only generates electricity during the day, while wind power can generate also by night, energy security might become an issue. Energy storage technologies must then be considered. However, as Das et al.'s study reviewed in section 2 projects similar installed power capacities as those of the CEA scenario and found that storage technologies will not play a significant part prior to 2030, the topic will not be further elaborated upon.

A situation in which neither of solar nor wind power meet their target values is also a likely outcome of the current development. Hence, the capacity projections of the CEA45% scenarios might be more realistic than the CEA scenario's. In order to obtain the 258 GW of solar power capacity projected for the CEA45%a scenario, in excess of 24 GW must be installed annually. To obtain the projected 129 GW of wind power capacity, 11 GW must be installed annually. The capacity projections of the CEA45%b scenario are obtained by annual solar and wind power capacity additions approximately half the sizes of the CEA45%a scenario's. However, as discussed above, the applied energy efficiency factors of the CEA45%b scenario are considered unrealistic. Also note that the projected development further decreases the likelihood of obtaining the capacity projections of the BAU scenario and PG scenario. Hence, as a conclusion to this subsection, the CEA scenario and the CEA45%a scenario stand out as the most likely, at least when only considering power sector projections. Subsequently, surpassing 500 GW of non-fossil fuel power capacity by 2030 (pledge 1) seems possible, while a 50% renewable share in power generation (pledge 2) seems highly unlikely. Additionally, although not being the focus of this study, India's NDC of increasing the share of non-fossil power capacity to 50% by 2030 seems highly likely to be fulfilled (CEA scenario/CEA45%a scenario: 67%).

5.2 Emission projections

Figure 20 presents the projected 2030 GHG emissions by demand category by scenario. 2015-values are added to the figure to serve as a reference. The BAU scenario projects emissions of 5.38 Gt CO_2e, the CEA scenario projects 4.53 Gt CO_2e, the PG scenario projects 4.25 Gt CO_2e, while the CEA45% scenarios project 4.17 Gt CO_2e. All scenarios assume a 2030 GDP of 4959 billion $US15, resulting in emission multipliers (in kg CO_2e per $US15) of 1.08, 0.91, 0.86 and 0.84, respectively. The corresponding emission multiplier changes compared to 2005 levels are -29%, -40%, -44% and -45%. The numbers are summarized in Table 10. The last row of the table is color coded to imply the status of fulfilling pledge 4 (45% decrease in emission multiplier compared to 2005 levels). As will discussed in detail, fulfilling pledge 4 is considered to be likely.

Regardless of scenario, Figure 20 shows that household consumption is expected to remain the main contributor to India's production-based emissions. However, when compared to the development between 1995 and 2015 (Figure 14), GFCF is projected to become a much larger source of emissions, almost equaling the emissions from households. In other words, capital expenditure by public and private sectors is expected to significantly increase towards 2030. This is in line with the projected doubling of real GDP from 2015 levels, as investments should increase concurrently with GDP levels.

As the BAU scenario is used as a reference scenario in which the remaining scenarios build on, it is valuable to know whether the emissions are in the same order of magnitude as the BAU projections found in other studies. As discussed in subsection 2.3, nine out of the ten papers presented in Table 2 only consider CO_2 and are thus not directly comparable to the BAU scenario. Hence, the calculations of the BAU scenario were repeated excluding all non-CO_2 GHGs. The resulting 2030 emissions were found to be 4.43 Gt CO_2, close to the median of the ten studies of

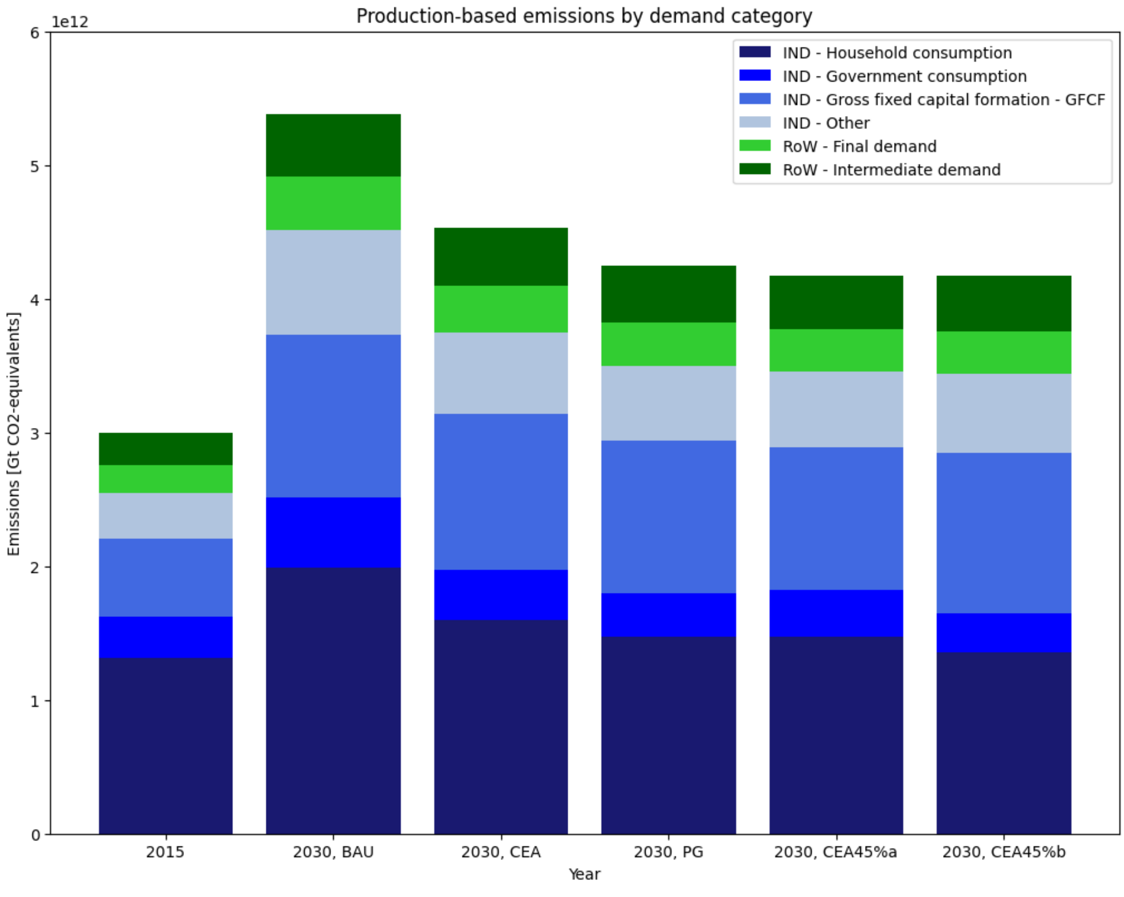


Figure 20: Projected production-based emissions, 2015-2030 [Gt CO_2e]

Table 10: Emission multiplier changes compared to 2005 levels by scenario

	BAU	CEA	PG	CEA45%a	CEA45%b
Emissions [Mt CO_2e]	5380	4528	4247	4170	4170
Emission multiplier [$\frac{kgCO_2e}{\$US15}$]	1.08	0.91	0.86	0.84	0.84
Emission multiplier change	**-29%**	**-40%**	**-44%**	**-45%**	**-45%**

4.57 Gt CO_2. The non-CO_2 emissions are projected to be 0.95 Gt CO_2e, which is in the same order of magnitude as the estimate of Shukla et al. - the only study in Table 2 not solely considering CO_2 - of 1.08 Gt CO_2e[32]. As Bakir et al.'s study reviewed in subsection 2.3 used a linear approach when projecting the 2030 electricity mix, their results are considered fitted to be directly compared to the BAU scenario[35]. The study projects non-CO_2 emissions of 0.98 Gt CO_2e, which is in line with the above numbers. They estimate total GHG emissions of approximately 5.12 Gt CO_2e assuming a renewable electricity share of 17%. Considering the BAU scenario projects a share of only 2%, 5.38 Gt CO_2e appears reasonable. In summary, the BAU scenario's results are in line with those of external sources, making it suitable to serve as a benchmark to measure the impact of climate policy actions.

The difference in the BAU and CEA scenario's projected emissions clearly illustrates the impacts of the electricity sector. In practice, the CEA scenario is simply a power sector-altered version of the BAU scenario. The difference lies in applied energy efficiency factors for all power generation technologies and an increased non-fossil electricity requirement share, from 6% to 40%. The changes constitute an emission decrease of 0.85 Gt CO_2e, a quite significant amount. The BAU scenario projects emissions from the electricity sector of 2.25 Gt, the CEA scenario projects 1.41 Gt, the PG scenario projects 1.14 Gt, the CEA45%a scenario projects 1.30 Gt and the CEA45%b scenario projects 1.44 Gt. The numbers correspond to total emission shares ranging from 27% (PG) to 42% (BAU). The two scenarios deemed most likely in subsection 5.1, the CEA scenario and the CEA45%a scenario, both have shares of 31%. The share is equal to that of 2015, when the power sector emissions were 0.92 Gt.

Figure 20 shows that India's export-related emissions are expected to significantly increase between 2015 and 2030. The background analysis in section 4 indicated that increasing exports volumes has a positive impact on India's emission multiplier. The export emission multipliers of the CEA scenario and the CEA45%a scenario are projected to be 0.91 and 0.84, respectively. The values are equal to their corresponding overall emission multipliers presented in Table 10. Hence, conflicting with what was indicated in section 4, exports and domestic demands are projected to have similar impacts on India's emission multiplier development towards 2030.

Coal is by far the most influential power generation technology when it comes to emissions. Even in the PG scenario in which coal has a relatively low generation share of 43%, the emissions from coal accounts for 92% of the total emissions originating from the power sector. Also note that the results of the PG scenario indicate that substantial changes in the power sector by itself is enough for India to obtain an emission multiplier decrease of 45%. In other words, the PG scenario will practically fulfill all three COP26 pledges. However, as subsection 5.1 revealed that the scenario is unlikely, it will only be further discussed when used as a reference for the other scenarios. The same goes for the BAU scenario.

As subsection 5.1 revealed that the CEA scenario and the CEA45%a scenario are the most realistic out of the five constructed, an emission multiplier decrease in excess of 40% seems likely. Considering that the results of section 4 indicate that the emission multiplier had decreased by more than 20% in the 10 years from 2005 to 2015, the development seems plausible. A linear development towards 2030 would have resulted in a projected decrease in excess of 50%. However, linearity is not a realistic assumption in such a complex system.

According to Figure 3 (Our World In Data[1] [2]) introduced in section 1, the emission multiplier in 2030 would have to be 0.97 kg CO_2e per \$US15 in order for pledge 4 to be fulfilled. As mentioned in section 4, using this number instead of the one obtained in the calculations of this thesis would make it easier to achieve an emission multiplier change of -45%. In fact, using Figure 3 as reference, the BAU scenario (-39%) is the only scenario not fulfilling pledge 4, as the CEA scenario's emission multiplier change is estimated to be -49%. This highlights the impact the choice of reference has on the obtained emission multiplier change. India's selected 2005-value used to officially evaluate pledge 4 will thus be crucial as to whether the pledge is fulfilled or not. Such a value was not stated in the country's third Biennial Update Report, in which the statement concerning the emission intensity of GDP dropping by 24% between 2005 and 2016 was published. However, the report state that the 2016 GHG emissions - excluding LULUCF - were 2839 Mt CO_2e[34]. Applying GDP data from Figure 2 (Our World In Data[2]), this is equivalent to a 2016 emission multiplier of 1.25. Subsequently, given a 24% decrease, the 2005 emission multiplier is found to be 1.64, which is in middle of the one found in this thesis (1.53) and the one found in Figure 3 (1.77). Using the one found in the Update Report, the CEA scenario will obtain an emission multiplier change of -45%, fulfilling pledge 4 by the slightest of margins. However, as the scenarios are constructed based on historical MRIO tables, and thus historical GDP and emission values, it is the most logical to give emphasis to the values obtained in this thesis. Nevertheless, the 2005 emission multiplier found in this thesis being the smallest out of the three identified indicates that pledge 4 might be easier to fulfill than what Table 10 suggests.

The CEA scenario illustrates that fulfilling pledge 1 has a significant positive impact on the emission multiplier but it is not enough to fulfill pledge 4. Hence, it might appear that pledge 1 will be easier to fulfill than pledge 4. However, there is not an enormous difference in the projected emissions of the CEA scenario and the PG scenario, yet the projected electricity mix of the PG scenario was deemed highly unlikely in subsection 5.1, while the CEA scenario's was considered feasible. In other words, the unrealistic added improvements from the CEA scenario to the PG scenario only results in a relatively small improvement in the emission multiplier. This highlights how other measures than renovating the electricity sector must contribute towards reaching a less carbon-intensive economy. Hence, while fulfilling pledge 1 significantly contributes towards fulfilling pledge 4, it is not crucial from an emission perspective that it is. In other words, an

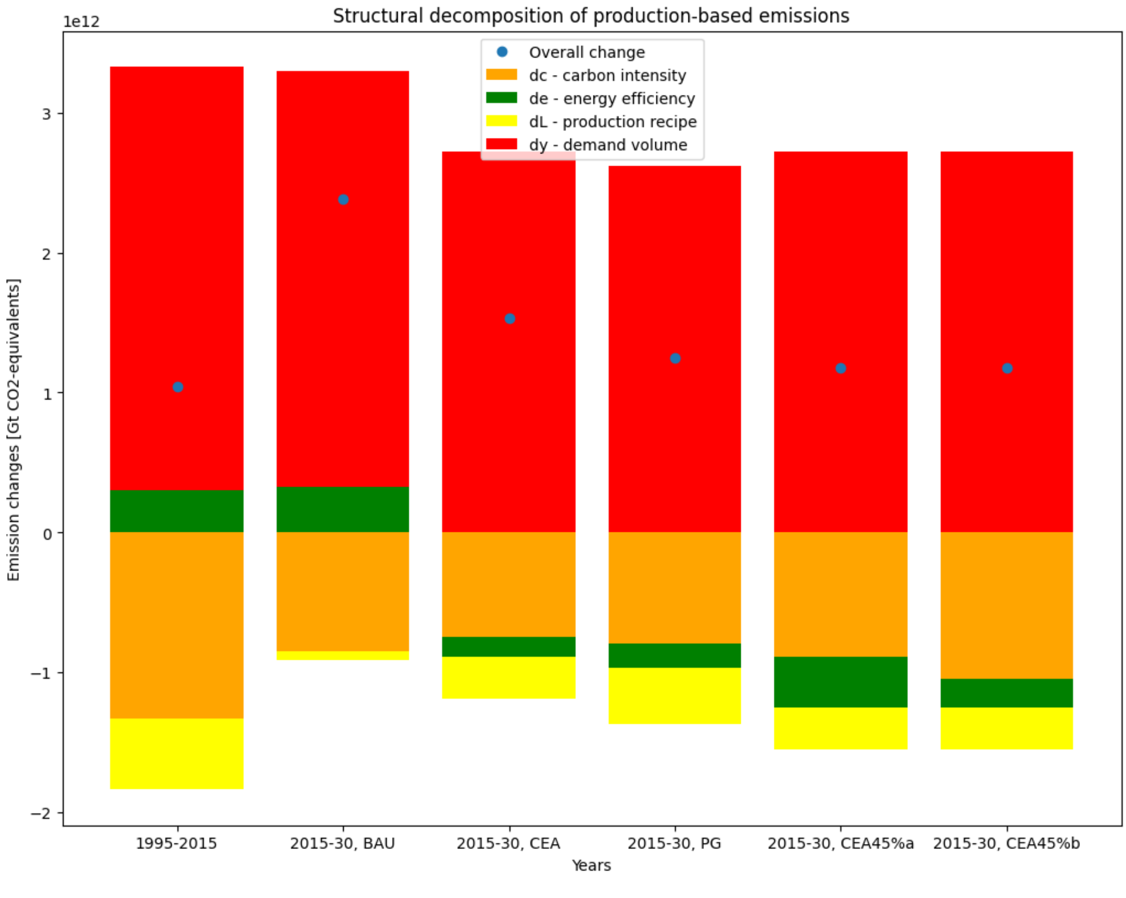


Figure 21: SDA of projected production-based emissions, 2015-2030 [Gt CO_2e]

Table 11: Drivers of changes in production-based emissions, 2015-2030 [Mt CO_2e]

Driving factor	BAU	CEA	PG	CEA45%a	CEA45%b
Carbon intensity	-850	-743	-796	-888	-1043
Energy efficiency	+329	-144	-166	-357	-203
Production recipe	-64	-302	-405	-302	-302
Demand volume	+2969	+2722	+2617	+2722	+2722
Sum	**+2384**	**+1533**	**+1251**	**+1175**	**+1175**

emission multiplier decrease of 45% can be achieved without pledge 1 and pledge 2 being fulfilled. This is illustrated by the CEA45% scenarios as neither of them fulfill the power sector goals due to energy efficiency improvements. In combination with carbon intensity improvements, the scenarios assume an overall increase in carbon efficiency of approximately 8%, which is required in order to fulfill pledge 4 using the CEA scenario as a basis. While the CEA45%a scenario assumes that all sectors have equal improvements of 4% within both energy efficiency and carbon intensity, the CEA45%b scenario assumes enhanced sector-wise improvements based on the SDA results of the CEA scenario. These are presented in Figure 21, which shows the SDA of every scenario's emission development between 2015 and 2030. SDA values of the period 1995-2015 are added to the figure to serve as a reference. The numbers are summarized in Table 11. The results show that the CEA scenario projects carbon intensity changes to contribute more towards decelerating the emission growth than energy efficiency changes. Subsequently, the CEA45%b scenario's additional overall improvements in carbon intensity and energy efficiency from the CEA scenario are estimated to be approximately 7% and 1%, respectively.

As expected, Figure 21 shows that the SDA of the BAU scenario has similar features as the one of the 1995-2015 period. The negative deltas of carbon intensity (c) and production recipe (**L**) partly offset the overall emission growth caused by the positive deltas of demand volume (y) and energy efficiency (e). Figure B1 and Figure F1 in the appendix present the most significant contributing sectors to the emission changes in the period 1995-2015 and for the BAU scenario, respectively. The fact that the overall most significant contributors are practically the same in the two figures indicates that the emission forecasting has been successful. This strengthens the BAU scenario's status as a credible reference scenario.

Figure 21 shows that the deltas of demand volume (+2.6 Gt to +3.0 Gt) and carbon intensity (-0.7 Gt to -1.0 Gt) remain in the same order of magnitude regardless of scenario. While the former can be expected due to all scenarios assuming the same 2030 GDP, the latter is surprising. Table 11 shows that carbon intensity's negative delta is in fact projected to be larger for the BAU scenario than for the CEA scenario. As carbon intensity is a measure for emissions per unit energy use and the CEA scenario is an improved power sector-altered version of the BAU scenario, this is an unexpected result. The reason is found looking at the most significant contributing sectors in Figure F1 and Figure H1 in the appendix. They show that the energy efficiency delta of the 'electricity by coal' sector is much larger in the BAU scenario (+435 Mt) than in the CEA scenario (+83 Mt). The energy efficiency deltas of the remaining sectors are relatively equal. The overall energy efficiency improvement from the BAU scenario to the CEA scenario causes the energy efficiency delta of coal-fired power to decrease. As energy use is the denominator when calculating carbon intensity, the increase in energy efficiency causes the carbon intensity delta of the 'electricity by coal' sector to increase from +48 Mt in the BAU scenario to +206 Mt in the CEA scenario, despite a relative carbon efficiency improvement within the sector. This highlights how carbon intensity and energy efficiency must be interpreted in light of each other.

Regardless of its relationship with carbon intensity change, the overall energy efficiency delta going from +0.3 Gt in the BAU scenario to being negative in the other scenarios is the most eye-catching result of Figure 21. As indicated above, this is mostly due to the 'electricity by coal' sector becoming more energy efficient as a result of the applied energy efficiency factors presented in Table 3. This especially applies for the CEA and PG scenario, as all sectors are affected by applied energy efficiency factors in the CEA45% scenarios.

In subsection 5.1 it was discussed that the electricity use changes caused by production recipe changes in the CEA- and CEA45%-scenarios are mainly results of solar power meeting the intersectoral demand previously met by coal-fired power. This is also the case for the projected **L**-delta for emission changes (Figure H1, Figure L1, Figure N1 in the appendix). However, while the **L**-delta is projected to be positive for the electricity use changes, it is projected to be negative for the emission changes. This is a direct result of the carbon intensity factor of 'electricity by coal' being much larger than that of 'electricity by solar'. In other words, renewable power meeting the demand previously met by coal-fired power increases the overall demand of electricity but simultaneously significantly decreases the emissions.

While the CEA scenario's 'electricity by coal'-**L**-delta is significantly negative (-528 Mt), the sector's y-delta is more than equivalently positive (+669 Mt), resulting in a projected overall increase in emissions of 141 Mt caused by the sector's increased output. The emission increase due to the sector's carbon efficiency development is projected to be 289 Mt, resulting in it being at top of the carbon efficiency change list. Despite relatively modest additions of coal-fired power capacity from 2015 levels, the decomposition factor deltas' sum of +429 Mt also makes the 'electricity by coal' sector the most significant contributor to the projected overall emission changes. Industrial sectors like 'basic iron and steel', 'other bituminous coal' and 'cement, lime and plaster' follow on the next places, mainly due to increased demand volumes and decreased energy efficiency levels. Waste treatment processes dominate in the other end of the list, mainly due to increased carbon efficiency levels. Figure L1 and Figure N1 in the appendix show that the same sectors dominate the lists of the CEA45% scenarios.

The combined emission changes due to carbon intensity and energy efficiency are projected to be -0.89 Gt for the CEA scenario and -1.25 Gt for the CEA45% scenarios. The deltas are three and four times larger than their corresponding **L**-deltas, which highlights carbon efficiency measures as the key to fulfilling pledge 4. Figure 21 shows that carbon intensity changes are assumed to be the main offsetting factor. This is a result of a projected continuation of the development seen in the SDA of the 1995-2015 period. In 1995, the average emissions per unit energy use (in kg CO_2e per kWh (kilowatt-hour)) of India's economy was 0.56. In 2005, the value had decreased to 0.50, and by 2015 the value was 0.43. The downward trend is confirmed comparing the results to external sources. Dividing India's emissions in Figure 1 (Our World In Data [1]) by its primary energy consumption in Figure 7 (Our World In Data [11]) yields a 1995-value of 0.49, a 2005-value of 0.42 and a 2015-value of 0.38. The 2019-value was 0.36, indicating that the development has continued to move in the right direction. As a reference, the global 2019 carbon intensity factor was 0.29, which highlights the room for improvement [1] [11]. It is noted that the values obtained in this thesis are consistently higher than the others. Nevertheless, it is the trend that is of importance. The BAU scenario projects a 2030 carbon intensity factor of 0.39, while the remaining scenarios project a value of approximately 0.34. Hence, it seems that a carbon intensity improvement in excess of 30% from 2005 levels will be required in order to fulfill pledge 4 following the trends of the last decades. Increasing shares of non-fossil energy sources will be key in reaching the target value.

Figure H1 and Figure L1 in the appendix show that the 'electricity by coal' sector is the most significant positive contributor to the overall carbon efficiency deltas of both the CEA scenario (+289 Mt) and the CEA45%a scenario (+184 Mt). As mentioned in subsection 5.1, the positive deltas are not in line with Chikkatur et al. and Garg & Shukla's finding concerning India's coal-fired power sector becoming more efficient [12] [13]. The studies - both published prior to 2010 - claim the sector experienced carbon efficiency improvement due to the implementation of international technology instead of the domestically produced subcritical power plants. However, numbers presented in 2020 by the International Energy Agency (IEA) show that the average design efficiency (i.e., coal consumption and emissions) of India's coal fleet remained at a relatively stable level (31%-34%) between 1995 and 2014 [61]. In fact, the efficiency dropped after 2002, not reaching the same levels until 2015. In 2016, the efficiency reached a record-high 37.2%, close to the global average of 37.5% [61]. Presenting similar arguments as Chikkatur et al. and Garg & Shukla, Trivedi's study from 2020 found the improvement to be due to additions of supercritical power plants and retirement of old, subcritical power plants [61]. While subcritical units at best reach efficiency levels of 37-38%, supercritical units can typically reach 42-43% due to steam being generated at pressure levels above the critical point of water [61]. Ultra-supercritical units operate at even higher pressures and temperatures and can reach efficiency levels of up to 45% [61]. Naturally, the capital costs of the units increase with the efficiency levels. However, generation costs decrease. The Indian government released a statement in March 2023 regarding a total supercritical capacity of 63.2 GW and a total ultra-supercritical capacity of 1.3 GW having been commissioned [62]. The statement also included a note regarding 18.3 GW of subcritical capacity having been retired by the end of 2022 [62]. The ratio of supercritical and ultra-supercritical technology replacing subcritical technology will naturally heavily influence the total 2030 coal-fired power capacity. As all new coal-fired power plants are required to have at least supercritical technology, the efficiency of India's coal fleet will continue to increase towards 2030 [61]. In addition, the Ministry of Power want to introduce biomass co-firing, meaning biomass and fossil fuels will be combusted together at thermal power plants [62]. Biomass co-firing is a well-proven technology and regarded the most economical way of utilizing biomass [61]. It demands minuscule investments but has significant emission reduction potential, resulting in further carbon efficiency improvement at a low price. As a result of the government's policies and plans the carbon efficiency delta of the 'electricity by coal' sector should be negative between 2015 and 2030. In other words, the overall carbon efficiency deltas should have a substantially larger offsetting effect than what is portrayed in Figure 21, making it easier to fulfill pledge 4. The inaccuracy is a consequence of the methodological choice of using the development in the period 1995-2015 to project 2030 values. Note that other sectors might experience opposite development, having had positive developments until 2015 and negative developments since. However, as the 'electricity by coal' sector has such a prominent influence on the emission changes it is natural to discuss it in isolation. Nevertheless, this illustrates how using historic data to forecast the future can cause illogical projected developments. This will be further discussed in subsection 5.3.

Additional energy efficiency measures within the electricity sector were covered in subsection 5.1. The power sector was identified as an industry with huge improvement potential, mostly due to large transmission and distribution losses. However, solely targeting energy efficiency improvements within the power sector, measures corresponding to a 25% improvement would be required in order to fulfill pledge 4 using the CEA scenario as a reference. In other words, the applied energy efficiency factors presented in Table 3 would be set to 0.75 for all power generation technologies. However, in practice, coal-fired power is the only one that would have to be 0.75 due to its dominating impact potential. Regardless, based on the discussion in subsection 5.1, such improvements seem unrealistic. Hence, energy efficiency measures within other sectors are required in order to advance from the 40% emission multiplier decrease of the CEA scenario to fulfilling pledge 4.

Vishwanathan et al.'s report reviewed in section 2 found the industrial sector to be the sector with the largest energy efficiency potential [22]. Further development of the PAT scheme was identified as key to obtaining energy savings. The Indian government has released the results of the first cycles of the scheme. Cycle I was initiated in 2012. By 2015, energy savings were estimated to be 101 TWh, translating into the avoidance of 31 Mt CO_2 [63]. Cycle II was initiated in 2016. By 2019, energy savings were estimated to be 154 TWh, translating into the avoidance of 61 Mt CO_2 [63]. Cycles III through VI were initiated between 2017 and 2020. The collective energy savings of the six cycles are estimated to be 302 TWh between 2020 and 2023, translating into the avoidance of approximately 70 Mt CO_2 [63]. Note that only CO_2 emissions are considered. Assuming that carbon intensity levels develop towards the 2030 value found above of 0.34 kg CO_2e per kWh, the PAT scheme is likely to lead to emission savings in excess of 0.4 Gt CO_2e in the period 2015-2030. Most of the savings will be due to increased efficiency in thermal power plants and iron, steel, aluminum, cement, fertilizer, pulp, and paper production processes [22]. Targeting these energy-intensive industries should by itself make it possible to exceed the CEA scenario's estimated overall e-delta of -144 Mt CO_2e between 2015 and 2030. Additional energy efficiency measures like advanced space cooling systems and cleaner cooking processes in the residential sector and increasing the share of electricity used in the transport sector should further reduce the emissions. This comes on top of the measures within the power sector. Hence, the CEA45%a scenario's e-delta of -357 Mt CO_2e appears realistic. Surpassing the delta and thus covering parts of the overall carbon efficiency improvement between the CEA scenario and the CEA45%a scenario originally projected to be covered by carbon intensity measures also seems plausible. Subsequently, the CEA45%a scenario must be considered to be as feasible as the CEA scenario. In fact, due to the lower required capacity additions of solar and wind power, it might be more feasible. Regardless, significant additional carbon efficiency improvements using the CEA scenario as a basis seems to be achievable. Hence, obtaining an emission multiplier decrease of 45% or more is considered to be likely.

5.3 Uncertainties

Forecasting the future accurately is a difficult task, and all MRIO projections must be handled as rough estimates. Table 5 showing a different electricity mix than presented by external sources exemplifies that even reproducing historical results accurately through MRIO tables is complicated. Hence, as the 2030 scenarios in this thesis build on historical trends found through MRIO calculations, it goes without saying that there is a lot of uncertainty related to the projections. This is illustrated by the electricity mix extracted from the BAU scenario - which is unaltered and entirely based on historical trends - quickly being identified in subsection 5.1 as highly unlikely. This conclusion makes room for the possibility of other less studied sectors' projections also being unlikely. Hence, the approach chosen to calculate projected growth rates within each sector can be considered an element of uncertainty. Instead of basing the projected developments on the average annual changes between the mean-values of 1995 and 2005 and 2015-values, a more dynamic approach could have been more appropriate. As an example, annual data from the 2005-2015 period could have been analyzed to identify each individual sector's detailed trend, which could then be used to forecast the future development pattern. In a revised study, such an approach would be considered. However, the electricity sector is identified as an industry currently experiencing huge changes and its outputs are thus impossible to accurately forecast solely applying historical data. It is implied that other sectors to a larger degree can more accurately be forecast based on previous trends. This is mostly due to the different subsectors of power generation technologies' varying expected developments making the overall electricity sector a complex industry to forecast. The electricity sector is also an industry with large emissions, making it crucial from an emission perspective that the projections are plausible. Hence, as it heavily impacts all three COP26 pledges evaluated, this thesis has focused on reducing the uncertainty of the power sector projections through thorough discussions. This section will mainly focus on further discussions of these uncertainties.

The literature review revealed a strong association between GDP levels and electricity requirements. However, in the CEA report in which the original 2030 power capacity mix projection of the CEA scenario and the overall projected electricity requirements of 2518 TWh were found, estimated 2030 GDP levels were not specified [5]. Out of the three papers reviewed in section 2 considered fitted to be compared to the electricity mixes of this thesis, Dasgupta & Sarangi's is the only one that specifies that real GDP growth rates are applied [20]. They project India's 2030 GDP to be 4643 billion $US15, assuming an overall annual power production of 2352 TWh. This study estimates the 2030 GDP to be 4959 billion $US15 and the electricity requirements to be likely to be between 2416 TWh (CEA45%a scenario) and 2518 TWh (CEA scenario). As both GDP levels and electricity requirements are slightly lower in Dasgupta & Sarangi's study, these results seem realistic. The relation between GDP levels and electricity requirements is thus regarded as accounted for in the calculations of this thesis.

While the projected 2030 GDP is assumed to be independent of efficiency gains, it is assumed that increased energy efficiency levels lead to proportionally decreased energy consumption in the calculations of this thesis. However, studies indicate that increased energy efficiency reduces energy costs which subsequently encourages higher energy consumption [64] [65]. The rebound effect weakens the efficiency gains. Simultaneously, it allows for further economic growth. This indicates that instead of lowering the energy consumption levels proportionally with the efficiency improvements, they should be lowered slightly while GDP levels should be increased. In other words - due to the efficiency gains using the CEA scenario as reference - the CEA45%a scenario's energy requirements and GDP should be slightly increased. Hence, the scenario's electricity requirements should also be slightly increased. However, as concluded in the above paragraph, the relation between the CEA45%a scenario's GDP levels and electricity requirements is in line with the results of Dasgupta & Sarangi's study [20]. Nevertheless, the relation between energy efficiency, energy consumption, and economic growth levels should be further analyzed in a revised study.

Due to it being considered the most feasible solution to obtain the total electricity requirements of 2518 TWh, the projected 2030 coal-fired power capacity was lowered from the original 267 GW in the CEA report to 228 GW in the CEA scenario. As discussed throughout subsection 5.1 and subsection 5.2, there is a lot of uncertainty related to this value as there are conflicting signals from the Indian government concerning coal's future in the electricity mix. Retiring subcritical units and replacing them with supercritical and ultra-supercritical units will increase the efficiency of India's coal fleet. This should lead to higher outputs per installed GW. However, the IEA's numbers discussed in subsection 5.2 suggest otherwise[61]. They state that the efficiency of India's coal fleet dropped after 2002, not reaching similar levels until 2015. This is not in line with coal power's annual generation per capacity trend presented in Figure 12 (Our World In Data/Ember[11] [15]), which shows an upwards trend between 2002 and 2009, before a significant drop until 2015. This highlights how design efficiencies are not the only factor influencing generation outputs. Which approach that is the most accurate in converting capacity projections to generation projections can be discussed. In this thesis, it was chosen to use the average values of a 21-year period (2000-2021) to account for the fluctuations. It can be argued that using a smaller, recent sample period would be a better approach. As an example, using 2016-2021 as a sample period, there would be no need to downscale the CEA's original coal-fired power capacity projection of 267 GW to meet the overall electricity requirements due a lower coal power 'generation per capacity'-value. At the same time, the values of bioenergy, gas, petroleum and solar would be lower than their applied values, while nuclear, hydro and wind would be higher. However, as mentioned in subsection 3.7, factors like scheduled maintenance, climate and weather, output reductions, and changes in demands, supplies and costs also impact the 'generation per capacity'-values, not only efficiency improvements. Subsection 5.1 revealing large variations in the 'generation per capacity'-values applied by Das et al., Dasgupta & Sarangi, and the CEA report highlights the uncertainty related to these values[5] [20] [36]. Hence, as there are a lot of elements of uncertainty, it is extremely difficult to project "correct" values. This naturally does not affect the capacity projections of the CEA and CEA45%a scenarios, but it has an impact on their electricity mix projections. However, as the renewable electricity share of 36% found for both scenarios is in line with the findings of the three studies mentioned above, the applied 'generation per capacity'-values are considered to be sufficiently accurate.

Subsection 5.1 revealed that the CEA45%b scenario's applied energy efficiency factors presented in Table 3 resulted in highly unlikely generation outputs. The scenario was thus regarded as unrealistic. The overall improvement of 4% from the CEA scenario to the CEA45%a scenario is on the other hand considered to be plausible, mostly due to expected reduced transmission and distribution losses equally affecting all power generation technologies' outputs. Hence, the uncertainty related to the CEA- and CEA45%a-scenario's applied energy efficiency factors are regarded as little.

The 'electricity by coal' sector is projected to be the sector with the largest positive delta affecting the overall emission changes. However, subsection 5.2 revealed that the sector's SDA results are believed to be inaccurate. The improvements within the sector should lead to negative carbon efficiency deltas, instead of the projected significantly positive ones. At the same time, section 4 revealed that the 2015-electricity mix presented in Table 5 had too large coal generation outputs compared to external sources. As the decomposition results are based on the development between 2015 and 2030, the overall emission output delta ($\mathbf{L}$ + y) of the 'electricity by coal' sector should be larger than the SDA results indicate, countering the offsetting effect of the expected carbon efficiency improvements. This highlights the uncertainty related to SDA results and how decomposition results must be handled carefully. However, this is just important from an SDA-perspective as the overall emission levels are unaffected by decomposition results. In other words, seen in isolation, the increase in coal-fired power outputs from 2015 levels is only relevant from an SDA-perspective. Hence, the argument of decreased emission changes within the sector due to efficiency improvements is still valid. Subsequently, even only assuming zero development in carbon efficiency levels since 2015, 0.3 Gt CO_2e can be removed from the CEA scenario's overall projected emissions. A small improvement would lead to the fulfillment of pledge 4, without further measures being required. This illustrates the impact potential of 'electricity by coal' sector, subsequently highlighting how inaccuracies in the sector's projections significantly affect the forecast emissions. As it also heavily influences the power sector pledges, coal-fired power's development towards 2030 is regarded the largest element of uncertainty in the projections of this thesis.

Lastly, subsection 5.2 revealed that the 2005 emission multiplier found in this thesis is smaller than the one presented by Our World In Data (Figure 3 [1] [2]) and the one used in India's third Biennial Update Report [34]. As the 2005-value is used as reference when evaluating pledge 4, this heavily influences the 2030 emission multiplier required to obtain a 45% decrease. As discussed in subsection 5.2, using the 2005-value calculated in this thesis is the most logical choice due to both historical results and future projections being based on MRIO tables. Using the smallest 2005 emission multiplier as reference also ensures that the projected emission multiplier changes are in the "pessimistic" end of the scale. In other words, the CEA scenario's projected 40% emission decrease is a "minimum" of what can be expected. This strengthens the conclusion concerning the fulfillment of pledge 4 being likely. Regardless, the 2005 reference-value used to officially evaluate pledge 4 must be considered a source of error as an official value is not provided.

5.4 Policy implications

The results of this thesis highlight changes within the electricity sector as the key in fulfilling all three COP26 pledges considered. Whether the pledges will be fulfilled or not heavily depends on the development within three sectors of power generation: coal, solar and wind. As discussed throughout this section, there is a lot of uncertainty related to coal-fired power's development towards 2030. The Ministry of Power should thus develop a clear roadmap including additions of advanced technology and retirement plans for outdated, sub-critical units. This would help clarify India's official expectations of its future coal fleet, signalizing the country's commitment to the agreed upon COP26 'coal phase down' deal. The Ministry of Power should also consider conducting an analysis of India's current coal fleet to identify outdated units suited for being renovated or transformed into biomass & waste power plants. As an alternative to demolishment, this could prove a resource-efficient measure resulting in emission savings. As another emission abatement measure, the Ministry's plans of biomass co-firing should be acted upon and further developed.

In accordance with the IEEFA's analysis, annual investments in renewable power towards 2030 must be more than doubled compared to current levels in order for India to fulfill pledge 1. The money is most beneficially invested in solar and wind power as they are considered the cheapest domestic electricity sources, even without subsidies [4]. However, investments could be advanced through provision of subsidies if the development in additions of renewable power capacity was to stagnate. Given the reduced social costs due to co-benefits like less air pollution and increased employment levels [20], this should be considered by the Indian government. Additionally, the government should consider introducing environmental taxes for energy-intensive industries, thereby promoting carbon efficient production structures. Efficiency measures within the residential sector is also a high impact opportunity due to India's enormous population. Hence, further development of the PAT scheme by introducing additional measures and including additional sectors is recommended.

Although not considered in the calculations of this thesis, the development and implementation of CCS technology is identified in previous studies as a measure with huge emission saving potential. As India's electricity mix is expected to remain coal-dominated, plans for implementing relevant CCS technology should be developed, preferably in close collaboration with countries that have expertise in carrying out such projects.

The sector-wise largest projected emission multipliers are found for the fossil fuel industry. Sectors like 'natural gas liquids', 'lignite/brown coal' and 'sub-bituminous coal' were among the ones found in the top spots throughout the 1995-2015 period, and subsequently in all 2030 scenarios. Service sectors like 'education services', 'health and social work services', 'real estate services' and 'public administration and defense services' dominate in the other ends of the lists. Expanding the service sectors will thus significantly increase India's GDP, while just slightly increase the emissions, and hence, contribute to an overall decrease in the emission multiplier. Of course, expanding the fossil fuel industry would have the opposite effect: a slight increase in GDP and a significant increase in emissions. Hence, the Indian government should focus on decelerating the growth in fossil fuel demands and investing in service sectors as it theoretically is the most efficient path towards fulfilling pledge 4.

5.5 External validity

External validity captures the extent to which inferences drawn from a given study can be generalized to make predictions about populations that were not studied [66].

India has a unique position in influencing future global emissions, having recently overtaken China to become the world's most populous country [67]. Apart from China - which is considered to be developmentally ahead of India - countries with similar potential increasing impacts on global emissions are scarce. However, considering similarities in development status and electricity mixes, Indonesia stands out as a country in a similar position. It has the world's fourth largest population, a coal-dominated electricity mix, and a similar Human Development Index (HDI) as India [11] [68] [69]. Additionally, the International Monetary Fund (IMF) has forecast India and Indonesia to be the two fastest-growing top-20 economies during the next five-year period (2023-2028) [70]. Given the countries' similar positions, the results concerning India's efficiency measures offsetting the growth in emissions might also be applicable for decreasing the carbon intensity of Indonesia's economy. Hence, the implications of this study might also be relevant to Indonesian policy makers.

6 Conclusion

India's COP26 pledges evaluated in this thesis are undoubtedly ambitious. Out of the five constructed 2030 scenarios, only the one specifically designed to fulfill both power sector pledges is projected to obtain a renewable generation share of 50%. However, the scenario is deemed unlikely, subsequently indicating that pledge 2 (50% of electricity requirements from renewable sources) is highly unlikely to be fulfilled. The renewable electricity generation share is estimated to be in the range of 30% to 40% by 2030. The two scenarios deemed the likeliest build on the Central Electricity Authority's power capacity projections, indicating that pledge 1 (500 GW of non-fossil fuel electricity capacity) is possible to fulfill. The results of this thesis indicate that fulfilling pledge 1 by itself is likely to result in an emission multiplier decrease of approximately 40% compared to 2005 levels. However, emission savings from expected additional carbon efficiency measures are projected to be substantial enough to surpass 45%, subsequently indicating that pledge 4 (45% decrease in emission multiplier compared to 2005 levels) is likely to be fulfilled.

The fulfillment of all three pledges heavily relies on significant capacity additions of solar and wind power, which will require annual investments towards 2030 twice the magnitude of current levels. The fulfillment of pledge 2 and pledge 4 will also require decelerated growth within the coal-fired power sector. Additionally, carbon efficiency measures are key in fulfilling pledge 4. The most significant measures include further development of the Perform, Achieve, Trade scheme through introducing additional measures and including additional sectors, reducing transmission and distribution losses, and replacing subcritical units with supercritical and ultra-supercritical units within the coal-fired power sector. Furthermore, in order to decrease the emission multiplier, Indian policy makers should introduce measures decelerating the growth in fossil fuel demands and increase investments in service sectors.

The Business-as-Usual scenario being similar to the 2030 Business-as-Usual projections of several external papers indicates that manipulating Multi-Regional Input-Output tables is a suitable method to forecast emissions. However, there are still several elements of uncertainty related to the projected 2030 tables, indicating that the quantitative results of this thesis must be handled as rough estimates. In a revised study, a more dynamic approach to project growth rates within each sector should be explored. Furthermore, future research should include further analysis of the expected relative developments of India's economic growth levels, energy efficiency, and energy consumption.

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Appendix

A Code & source of data

The calculations of this thesis were performed in the web-based interactive development environment JupyterLab through Cloudio. Cloudio is a virtual machine designed to meet the computational needs of the researchers at the Industrial Ecology Programme. Python was used as programming language. The Jupyter Notebook file 'India2030.ipynb' and its corresponding PDF are attached.

The EXIOBASE MRIO tables can be downloaded from zenodo.org.

B Tables: SDA, emissions, 1995-2015

sector	Mt CO2-eq
Cattle	-15.361038
Crops nec	-9.350842
Nickel ores and concentrates	-8.368357
Other business services (74)	-7.370633
Computer and related services (72)	-3.970001
...	...
Raw milk	21.418931
Cement, lime and plaster	30.846898
Other Bituminous Coal	36.986492
Paddy rice	41.471304
Electricity by coal	172.727944

(a) 1995-2005, total

sector	Mt CO2-eq
Crude petroleum and services related to crude oil extraction, excluding surveying	-6.561354
Crops nec	-5.624628
Cattle	-4.694275
Natural Gas Liquids	-3.696446
Electricity by petroleum and other oil derivatives	-3.690941
...	...
Raw milk	24.868780
Cement, lime and plaster	91.546395
Other Bituminous Coal	98.909320
Basic iron and steel and of ferro-alloys and first products thereof	110.215602
Electricity by coal	431.566022

(b) 2005-2015, total

sector	Mt CO2-eq
Paddy rice	-699.537551
Cattle	-192.506508
Raw milk	-38.123308
Electricity by coal	-24.135433
Cereal grains nec	-9.165769
...	...
Wheat	8.931976
Oil seeds	16.195383
Vegetables, fruit, nuts	32.241793
Food waste for treatment: waste water treatment	80.306384
Other waste for treatment: waste water treatment	95.454030

(c) 1995-2005, carbon intensity (c)

sector	Mt CO2-eq
Vegetables, fruit, nuts	-420.270415
Raw milk	-178.769360
Paddy rice	-149.656899
Oil seeds	-119.421278
Other Bituminous Coal	-28.718091
...	...
Crude petroleum and services related to crude oil extraction, excluding surveying	11.470874
Electricity by coal	51.376631
Food waste for treatment: waste water treatment	74.338600
Other waste for treatment: waste water treatment	86.470539
Cattle	157.767090

(d) 2005-2015, carbon intensity (c)

sector	Mt CO2-eq
Other waste for treatment: waste water treatment	-117.994034
Food waste for treatment: waste water treatment	-101.868522
Cattle	-61.935883
Vegetables, fruit, nuts	-33.007188
Cement, lime and plaster	-30.052680
...	...
Cereal grains nec	13.458170
Crude petroleum and services related to crude oil extraction, excluding surveying	14.518321
Other Bituminous Coal	20.279359
Electricity by coal	129.818063
Paddy rice	616.295179

(e) 1995-2005, energy efficiency (e)

sector	Mt CO2-eq
Cattle	-311.583477
Other waste for treatment: waste water treatment	-184.944793
Food waste for treatment: waste water treatment	-157.600393
Paddy rice	-69.024038
Crude petroleum and services related to crude oil extraction, excluding surveying	-32.069508
...	...
Basic iron and steel and of ferro-alloys and first products thereof	62.113154
Raw milk	82.036180
Oil seeds	105.943154
Electricity by coal	115.288364
Vegetables, fruit, nuts	410.989693

(f) 2005-2015, energy efficiency (e)

sector	Mt CO2-eq
Electricity by coal	-220.762816
Cement, lime and plaster	-45.398603
Other Bituminous Coal	-36.210355
Basic iron and steel and of ferro-alloys and first products thereof	-22.063049
Crude petroleum and services related to crude oil extraction, excluding surveying	-19.788973
...	...
Gas/Diesel Oil	6.151406
Wheat	8.340391
Aluminium ores and concentrates	10.561920
Cattle	47.176078
Paddy rice	123.637673

(g) 1995-2005, production recipe (**L**)

sector	Mt CO2-eq
Electricity by coal	-339.483515
Electricity by gas	-22.240225
Natural Gas Liquids	-15.835144
Crude petroleum and services related to crude oil extraction, excluding surveying	-14.747242
Gas/Diesel Oil	-10.980963
...	...
Other waste for treatment: waste water treatment	15.824438
Basic iron and steel and of ferro-alloys and first products thereof	17.008060
Raw milk	23.868322
Paddy rice	29.358846
Cattle	33.344889

(h) 2005-2015, production recipe (**L**)

sector	Mt CO2-eq
Natural gas and services related to natural gas extraction, excluding surveying	-4.136968
Natural Gas Liquids	-1.001326
Wheat	-0.904488
Meat animals nec	-0.412948
Collected and purified water, distribution services of water (41)	-0.128333
...	...
Other Bituminous Coal	54.309133
Raw milk	55.521092
Cement, lime and plaster	99.328538
Cattle	191.905274
Electricity by coal	287.808130

(i) 1995-2005, demand volume (y)

sector	Mt CO2-eq
Products of forestry, logging and related services (02)	-0.318854
Iron ores	-0.309175
BKB/Peat Briquettes	-0.062769
Other non-ferrous metal ores and concentrates	-0.052490
Hotel and restaurant services (55)	-0.043965
...	...
Raw milk	97.733638
Other waste for treatment: waste water treatment	104.931809
Cattle	115.777224
Paddy rice	197.335378
Electricity by coal	604.384542

(j) 2005-2015, demand volume (y)

Figure B1: Most significant contributors to emission changes, 1995-2015 [Mt CO_2e]

C Tables: SDA, electricity use, 1995-2015

sector	TWh
Electricity by petroleum and other oil derivatives	-5.788472
Electricity by solar photovoltaic	-1.858688
Electricity by wind	-0.872484
Electricity by biomass and waste	0.016439
Electricity by hydro	10.535196
Electricity by nuclear	10.988424
Electricity by gas	22.889643
Electricity by coal	243.978425

(a) 1995-2005, total

sector	TWh
Electricity by petroleum and other oil derivatives	-7.390614
Electricity by biomass and waste	0.388900
Electricity by solar photovoltaic	1.019302
Electricity by gas	1.768711
Electricity by hydro	4.791709
Electricity by wind	6.360089
Electricity by nuclear	29.548794
Electricity by coal	580.895038

(b) 2005-2015, total

sector	TWh
Electricity by wind	-11.053667
Electricity by petroleum and other oil derivatives	-10.589118
Electricity by solar photovoltaic	-2.528579
Electricity by biomass and waste	0.009641
Electricity by gas	4.355425
Electricity by nuclear	7.479365
Electricity by hydro	8.696922
Electricity by coal	157.998040

(c) 1995-2005, energy efficiency (e)

sector	TWh
Electricity by gas	-31.227693
Electricity by hydro	-8.776605
Electricity by petroleum and other oil derivatives	-4.658005
Electricity by biomass and waste	0.320536
Electricity by solar photovoltaic	0.413005
Electricity by wind	3.578707
Electricity by nuclear	9.795169
Electricity by coal	160.447612

(d) 2005-2015, energy efficiency (e)

sector	TWh
Electricity by coal	-268.684430
Electricity by petroleum and other oil derivatives	-16.211305
Electricity by gas	-12.169720
Electricity by hydro	-8.100609
Electricity by nuclear	-7.868142
Electricity by solar photovoltaic	-0.688841
Electricity by biomass and waste	-0.038096
Electricity by wind	7.416106

(e) 1995-2005, production recipe (**L**)

sector	TWh
Electricity by coal	-472.461549
Electricity by gas	-45.700059
Electricity by petroleum and other oil derivatives	-20.687040
Electricity by hydro	-18.937222
Electricity by nuclear	-17.391554
Electricity by wind	-0.933201
Electricity by biomass and waste	0.022407
Electricity by solar photovoltaic	0.176354

(f) 2005-2015, production recipe (**L**)

sector	TWh
Electricity by biomass and waste	0.044894
Electricity by solar photovoltaic	1.358732
Electricity by wind	2.765077
Electricity by hydro	9.938882
Electricity by nuclear	11.377200
Electricity by petroleum and other oil derivatives	21.011951
Electricity by gas	30.703938
Electricity by coal	354.664815

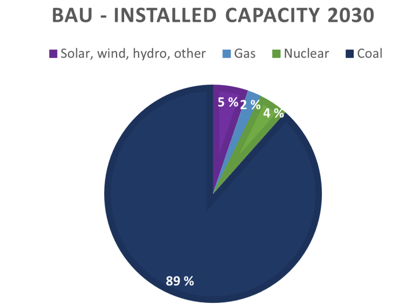
(g) 1995-2005, demand volume (y)

sector	TWh
Electricity by biomass and waste	0.045956
Electricity by solar photovoltaic	0.429944
Electricity by wind	3.714583
Electricity by petroleum and other oil derivatives	17.954430
Electricity by hydro	32.505536
Electricity by nuclear	37.145180
Electricity by gas	78.696463
Electricity by coal	892.908976

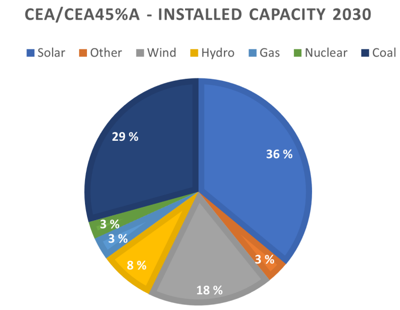
(h) 2005-2015, demand volume (y)

Figure C1: Most significant contributors to electricity use changes, 1995-2015 [TWh]

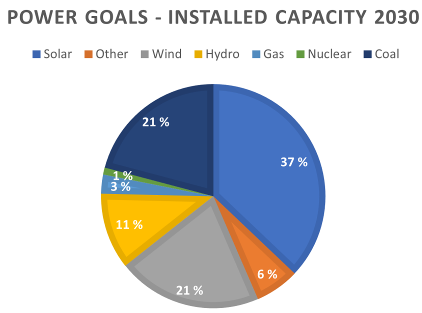
D Capacity shares of power generation technologies by scenario



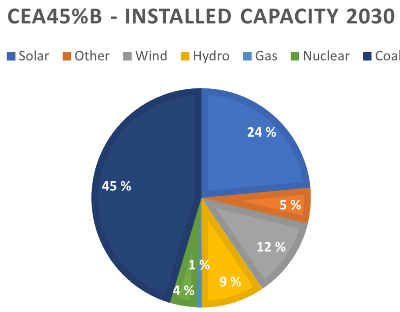
(a) BAU



(b) CEA/CEA45%a



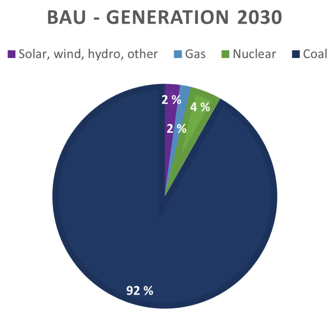
(c) Power goals



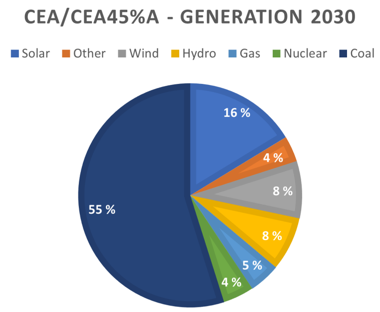
(d) CEA45%b

Figure D1: Capacity shares of power generation technologies by scenario

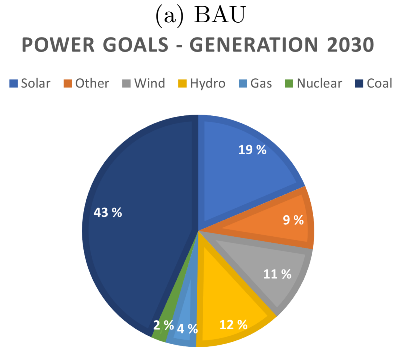
E Generation shares of power generation technologies by scenario



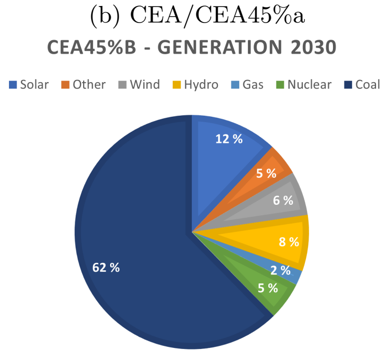
(a) BAU



(b) CEA/CEA45%a



(c) Power goals



(d) CEA45%b

Figure E1: Generation shares of power generation technologies by scenario

F Tables: SDA, emissions, 2015-2030: BAU

sector	Mt CO2-eq
Other waste for treatment: waste water treatment	-112.210438
Raw milk	-103.764752
Food waste for treatment: waste water treatment	-100.133192
Crude petroleum and services related to crude oil extraction, excluding surveying	-14.948664
Air transport services (62)	-10.484013
...	...
Fabricated metal products, except machinery and equipment (28)	71.197989
Cement, lime and plaster	173.525037
Other Bituminous Coal	240.445236
Basic iron and steel and of ferro-alloys and first products thereof	255.427571
Electricity by coal	1320.301300

(a) 2015-2030, total

sector	Mt CO2-eq
Raw milk	-321.141728
Paddy rice	-299.146361
Other waste for treatment: waste water treatment	-148.088652
Food waste for treatment: waste water treatment	-130.999765
Other Bituminous Coal	-42.525222
...	...
Cement, lime and plaster	13.996197
Furniture; other manufactured goods n.e.c. (36)	21.465353
Wood and products of wood and cork (except furniture); articles of straw and plaiting materials (20)	24.579658
Electricity by coal	47.507975
Hotel and restaurant services (55)	66.436473

(b) 2015-2030, carbon intensity (c)

sector	Mt CO2-eq
Cattle	-119.094598
Other waste for treatment: waste water treatment	-95.957529
Food waste for treatment: waste water treatment	-81.482006
Hotel and restaurant services (55)	-50.063160
Air transport services (62)	-28.319042
...	...
Raw milk	74.133456
Other Bituminous Coal	103.455156
Basic iron and steel and of ferro-alloys and first products thereof	103.835759
Paddy rice	108.675019
Electricity by coal	435.353477

(c) 2015-2030, energy efficiency (e)

sector	Mt CO2-eq
Electricity by coal	-132.189696
Other Bituminous Coal	-16.182201
Cement, lime and plaster	-10.008796
Natural Gas Liquids	-6.627066
Crude petroleum and services related to crude oil extraction, excluding surveying	-6.367709
...	...
Food waste for treatment: waste water treatment	7.336095
Other waste for treatment: waste water treatment	8.399662
Cattle	12.876780
Basic iron and steel and of ferro-alloys and first products thereof	15.741382
Paddy rice	48.125962

(d) 2015-2030, production recipe (**L**)

sector	Mt CO2-eq
Extra-territorial organizations and bodies	0.000000
Oil/hazardous waste for treatment: incineration	0.000000
Wood waste for treatment: incineration	0.000000
Textiles waste for treatment: incineration	0.000000
Other Hydrocarbons	0.000000
...	...
Cattle	156.913178
Cement, lime and plaster	172.391959
Paddy rice	195.430776
Other Bituminous Coal	195.697503
Electricity by coal	969.629543

(e) 2015-2030, demand volume (y)

Figure F1: Most significant contributors to emission changes, 2015-2030: BAU [Mt CO_2e]

G Tables: SDA, electricity use, 2015-2030: BAU

sector	TWh
Electricity by gas	-6.047919
Electricity by petroleum and other oil derivatives	-0.142884
Electricity by solar photovoltaic	0.496416
Electricity by biomass and waste	1.169610
Electricity by wind	2.771396
Electricity by hydro	17.992061
Electricity by nuclear	77.297228
Electricity by coal	1501.656085

(a) 2015-2030, total

sector	TWh
Electricity by gas	-52.044342
Electricity by wind	-6.181796
Electricity by petroleum and other oil derivatives	-3.341889
Electricity by hydro	-2.934358
Electricity by solar photovoltaic	-0.981543
Electricity by biomass and waste	0.694377
Electricity by nuclear	31.436531
Electricity by coal	537.402762

(b) 2015-2030, energy efficiency (e)

sector	TWh
Electricity by coal	-163.175698
Electricity by gas	-6.031769
Electricity by nuclear	-5.629378
Electricity by hydro	-3.922112
Electricity by petroleum and other oil derivatives	-2.720646
Electricity by biomass and waste	0.097992
Electricity by solar photovoltaic	0.234169
Electricity by wind	0.480277

(c) 2015-2030, production recipe (**L**)

sector	TWh
Electricity by biomass and waste	0.377241
Electricity by solar photovoltaic	1.243791
Electricity by petroleum and other oil derivatives	5.919652
Electricity by wind	8.472915
Electricity by hydro	24.848531
Electricity by nuclear	51.490075
Electricity by gas	52.028193
Electricity by coal	1127.429021

(d) 2015-2030, demand volume (y)

Figure G1: Most significant contributors to electricity use changes, 2015-2030: BAU [TWh]

H Tables: SDA, emissions, 2015-2030: CEA

sector	Mt CO2-eq
Other waste for treatment: waste water treatment	-112.359532
Raw milk	-104.181817
Food waste for treatment: waste water treatment	-100.220702
Crude petroleum and services related to crude oil extraction, excluding surveying	-14.949482
Air transport services (62)	-10.520262
...	...
Fabricated metal products, except machinery and equipment (28)	70.271629
Cement, lime and plaster	171.008870
Other Bituminous Coal	237.299404
Basic iron and steel and of ferro-alloys and first products thereof	252.175012
Electricity by coal	429.228116

(a) 2015-2030, total

sector	Mt CO2-eq
Raw milk	-318.898246
Paddy rice	-297.064370
Other waste for treatment: waste water treatment	-146.977746
Food waste for treatment: waste water treatment	-130.013695
Electricity by solar photovoltaic	-59.143456
...	...
Cement, lime and plaster	13.894834
Furniture; other manufactured goods n.e.c. (36)	21.294200
Wood and products of wood and cork (except furniture); articles of straw and plaiting materials (20)	24.385602
Hotel and restaurant services (55)	65.866746
Electricity by coal	206.176148

(b) 2015-2030, carbon intensity (c)

sector	Mt CO2-eq
Cattle	-118.169046
Other waste for treatment: waste water treatment	-95.237691
Food waste for treatment: waste water treatment	-80.868669
Electricity by gas	-78.260514
Electricity by solar photovoltaic	-58.239656
...	...
Raw milk	73.615563
Electricity by coal	82.574637
Other Bituminous Coal	102.692929
Basic iron and steel and of ferro-alloys and first products thereof	103.007641
Paddy rice	107.918665

(c) 2015-2030, energy efficiency (e)

sector	Mt CO2-eq
Electricity by coal	-528.463128
Cement, lime and plaster	-10.072276
Natural Gas Liquids	-6.588995
Crude petroleum and services related to crude oil extraction, excluding surveying	-6.482175
Distribution and trade services of electricity	-5.814630
...	...
Electricity by wind	12.820918
Basic iron and steel and of ferro-alloys and first products thereof	15.168668
Electricity by gas	42.792353
Paddy rice	47.360041
Electricity by solar photovoltaic	89.389102

(d) 2015-2030, production recipe (**L**)

sector	Mt CO2-eq
Extra-territorial organizations and bodies	0.000000
Food waste for treatment: incineration	0.000000
Wood waste for treatment: incineration	0.000000
Textiles waste for treatment: incineration	0.000000
Other Hydrocarbons	0.000000
...	...
Cattle	154.699414
Cement, lime and plaster	170.019962
Other Bituminous Coal	181.937410
Paddy rice	192.550672
Electricity by coal	668.940458

(e) 2015-2030, demand volume (y)

Figure H1: Most significant contributors to emission changes, 2015-2030: CEA [Mt CO_2e]

I Tables: SDA, electricity use, 2015-2030: CEA

sector	TWh
Electricity by petroleum and other oil derivatives	2.086849
Electricity by gas	61.072566
Electricity by nuclear	61.337846
Electricity by biomass and waste	85.507697
Electricity by hydro	170.036256
Electricity by wind	200.248256
Electricity by coal	206.302420
Electricity by solar photovoltaic	409.600104

(a) 2015-2030, total

sector	TWh
Electricity by solar photovoltaic	-337.219916
Electricity by wind	-170.979361
Electricity by gas	-166.334431
Electricity by hydro	-46.307035
Electricity by petroleum and other oil derivatives	-6.631877
Electricity by nuclear	13.882003
Electricity by biomass and waste	29.416375
Electricity by coal	101.964005

(b) 2015-2030, energy efficiency (e)

sector	TWh
Electricity by coal	-652.551668
Electricity by nuclear	-4.369994
Electricity by petroleum and other oil derivatives	-1.077004
Electricity by biomass and waste	55.716211
Electricity by gas	90.950614
Electricity by hydro	101.654668
Electricity by wind	207.692544
Electricity by solar photovoltaic	517.581788

(c) 2015-2030, production recipe (**L**)

sector	TWh
Electricity by biomass and waste	0.375111
Electricity by petroleum and other oil derivatives	9.795730
Electricity by nuclear	51.825837
Electricity by hydro	114.688623
Electricity by gas	136.456383
Electricity by wind	163.535073
Electricity by solar photovoltaic	229.238232
Electricity by coal	756.890082

(d) 2015-2030, demand volume (y)

Figure I1: Most significant contributors to electricity use changes, 2015-2030: CEA [TWh]

J Tables: SDA, emissions, 2015-2030: power goals

sector	Mt CO2-eq
Other waste for treatment: waste water treatment	-112.427424
Raw milk	-104.371727
Food waste for treatment: waste water treatment	-100.260552
Crude petroleum and services related to crude oil extraction, excluding surveying	-14.949855
Air transport services (62)	-10.536768
...	...
Fabricated metal products, except machinery and equipment (28)	69.849790
Electricity by coal	151.044835
Cement, lime and plaster	169.863252
Other Bituminous Coal	235.866971
Basic iron and steel and of ferro-alloys and first products thereof	250.685154

(a) 2015-2030, total

sector	Mt CO2-eq
Raw milk	-317.876678
Paddy rice	-296.116397
Other waste for treatment: waste water treatment	-146.471874
Food waste for treatment: waste water treatment	-129.564667
Electricity by solar photovoltaic	-67.683971
...	...
Cement, lime and plaster	13.848683
Furniture; other manufactured goods n.e.c. (36)	21.216271
Wood and products of wood and cork (except furniture); articles of straw and plaiting materials (20)	24.297482
Hotel and restaurant services (55)	65.607370
Electricity by coal	162.906606

(b) 2015-2030, carbon intensity (c)

sector	Mt CO2-eq
Cattle	-117.747586
Other waste for treatment: waste water treatment	-94.909900
Food waste for treatment: waste water treatment	-80.589374
Electricity by gas	-74.141489
Electricity by solar photovoltaic	-66.649660
...	...
Electricity by coal	65.244957
Raw milk	73.379741
Other Bituminous Coal	102.345855
Basic iron and steel and of ferro-alloys and first products thereof	102.628316
Paddy rice	107.574282

(c) 2015-2030, energy efficiency (e)

sector	Mt CO2-eq
Electricity by coal	-651.116017
Cement, lime and plaster	-10.074613
Natural Gas Liquids	-6.568594
Crude petroleum and services related to crude oil extraction, excluding surveying	-6.521530
Distribution and trade services of electricity	-5.787273
...	...
Basic iron and steel and of ferro-alloys and first products thereof	14.931712
Electricity by wind	16.634849
Electricity by gas	39.190940
Paddy rice	47.011379
Electricity by solar photovoltaic	102.338646

(d) 2015-2030, production recipe (**L**)

sector	Mt CO2-eq
Extra-territorial organizations and bodies	0.000000
Food waste for treatment: incineration	0.000000
Wood waste for treatment: incineration	0.000000
Textiles waste for treatment: incineration	0.000000
Other Hydrocarbons	0.000000
...	...
Cattle	153.714813
Cement, lime and plaster	168.913421
Other Bituminous Coal	177.297790
Paddy rice	191.239224
Electricity by coal	574.009289

(e) 2015-2030, demand volume (y)

Figure J1: Most significant contributors to emission changes, 2015-2030: power goals [Mt CO_2e]

K Tables: SDA, electricity use, 2015-2030: power goals

sector	TWh
Electricity by coal	-84.090943
Electricity by nuclear	0.198635
Electricity by petroleum and other oil derivatives	2.084483
Electricity by gas	55.089227
Electricity by biomass and waste	215.053196
Electricity by wind	259.483181
Electricity by hydro	279.587591
Electricity by solar photovoltaic	468.786623

(a) 2015-2030, total

sector	TWh
Electricity by solar photovoltaic	-385.802718
Electricity by wind	-219.601897
Electricity by gas	-157.533782
Electricity by hydro	-72.210641
Electricity by petroleum and other oil derivatives	-6.629935
Electricity by nuclear	6.420542
Electricity by biomass and waste	73.756448
Electricity by coal	80.541571

(b) 2015-2030, energy efficiency (e)

sector	TWh
Electricity by coal	-803.769509
Electricity by nuclear	-33.740540
Electricity by petroleum and other oil derivatives	-1.059777
Electricity by gas	83.271824
Electricity by biomass and waste	140.920809
Electricity by hydro	174.803011
Electricity by wind	269.397507
Electricity by solar photovoltaic	592.389043

(c) 2015-2030, production recipe (**L**)

sector	TWh
Electricity by biomass and waste	0.375939
Electricity by petroleum and other oil derivatives	9.774194
Electricity by nuclear	27.518633
Electricity by gas	129.351185
Electricity by hydro	176.995221
Electricity by wind	209.687572
Electricity by solar photovoltaic	262.200298
Electricity by coal	639.136995

(d) 2015-2030, demand volume (y)

Figure K1: Most significant contributors to electricity use changes, 2015-2030: power goals [TWh]

L Tables: SDA, emissions, 2015-2030: CEA45%a

sector	Mt CO2-eq
Other waste for treatment: waste water treatment	-113.917864
Raw milk	-108.865203
Food waste for treatment: waste water treatment	-101.132230
Crude petroleum and services related to crude oil extraction, excluding surveying	-14.959393
Air transport services (62)	-10.866226
...	...
Fabricated metal products, except machinery and equipment (28)	61.184199
Cement, lime and plaster	143.760385
Other Bituminous Coal	203.816810
Basic iron and steel and of ferro-alloys and first products thereof	220.213320
Electricity by coal	324.511828

(a) 2015-2030, total

sector	Mt CO2-eq
Raw milk	-308.336166
Paddy rice	-297.897568
Other waste for treatment: waste water treatment	-141.815836
Food waste for treatment: waste water treatment	-125.218899
Electricity by solar photovoltaic	-57.216039
...	...
Chemicals nec	9.444580
Furniture; other manufactured goods n.e.c. (36)	18.843347
Wood and products of wood and cork (except furniture); articles of straw and plaiting materials (20)	21.719824
Hotel and restaurant services (55)	60.153907
Electricity by coal	146.583573

(b) 2015-2030, carbon intensity (c)

sector	Mt CO2-eq
Cattle	-126.507389
Other waste for treatment: waste water treatment	-101.957933
Food waste for treatment: waste water treatment	-86.574992
Electricity by gas	-80.405438
Electricity by solar photovoltaic	-61.099876
...	...
Electricity by coal	37.450925
Raw milk	58.370097
Paddy rice	82.596584
Other Bituminous Coal	83.905579
Basic iron and steel and of ferro-alloys and first products thereof	85.995339

(c) 2015-2030, energy efficiency (e)

sector	Mt CO2-eq
Electricity by coal	-528.463128
Cement, lime and plaster	-10.072276
Natural Gas Liquids	-6.588995
Crude petroleum and services related to crude oil extraction, excluding surveying	-6.482175
Distribution and trade services of electricity	-5.814630
...	...
Electricity by wind	12.820918
Basic iron and steel and of ferro-alloys and first products thereof	15.168668
Electricity by gas	42.792353
Paddy rice	47.360041
Electricity by solar photovoltaic	89.389102

(d) 2015-2030, production recipe (**L**)

sector	Mt CO2-eq
Extra-territorial organizations and bodies	0.000000
Food waste for treatment: incineration	0.000000
Wood waste for treatment: incineration	0.000000
Textiles waste for treatment: incineration	0.000000
Other Hydrocarbons	0.000000
...	...
Cattle	154.699414
Cement, lime and plaster	170.019962
Other Bituminous Coal	181.937410
Paddy rice	192.550672
Electricity by coal	668.940458

(e) 2015-2030, demand volume (y)

Figure L1: Most significant contributors to emission changes, 2015-2030: CEA45%a [Mt CO_2e]

M Tables: SDA, electricity use, 2015-2030: CEA45%a

sector	TWh
Electricity by petroleum and other oil derivatives	1.758881
Electricity by gas	56.482009
Electricity by nuclear	56.720394
Electricity by biomass and waste	82.018951
Electricity by coal	150.195163
Electricity by hydro	162.086410
Electricity by wind	191.792777
Electricity by solar photovoltaic	392.923495

(a) 2015-2030, total

sector	TWh
Electricity by solar photovoltaic	-353.677697
Electricity by wind	-179.323889
Electricity by gas	-170.843247
Electricity by hydro	-54.186043
Electricity by petroleum and other oil derivatives	-6.955541
Electricity by nuclear	9.293766
Electricity by biomass and waste	25.944165
Electricity by coal	46.231257

(b) 2015-2030, energy efficiency (e)

sector	TWh
Electricity by coal	-652.360773
Electricity by nuclear	-4.368715
Electricity by petroleum and other oil derivatives	-1.076689
Electricity by biomass and waste	55.699912
Electricity by gas	90.924007
Electricity by hydro	101.624930
Electricity by wind	207.631787
Electricity by solar photovoltaic	517.430378

(c) 2015-2030, production recipe (**L**)

sector	TWh
Electricity by biomass and waste	0.374873
Electricity by petroleum and other oil derivatives	9.791111
Electricity by nuclear	51.795344
Electricity by hydro	114.647524
Electricity by gas	136.401249
Electricity by wind	163.484879
Electricity by solar photovoltaic	229.170814
Electricity by coal	756.324680

(d) 2015-2030, demand volume (y)

Figure M1: Most significant contributors to electricity use changes, 2015-2030: CEA45%a [TWh]

N Tables: SDA, emissions, 2015-2030: CEA45%b

sector	Mt CO2-eq
Other waste for treatment: waste water treatment	-209.979426
Raw milk	-203.037900
Food waste for treatment: waste water treatment	-185.212453
Electricity by solar photovoltaic	-35.699779
Crude petroleum and services related to crude oil extraction, excluding surveying	-25.513654
...	...
Fabricated metal products, except machinery and equipment (28)	78.405029
Cement, lime and plaster	175.466850
Other Bituminous Coal	261.675021
Basic iron and steel and of ferro-alloys and first products thereof	286.664625
Electricity by coal	545.603114

(a) 2015-2030, total

sector	Mt CO2-eq
Raw milk	-447.423550
Paddy rice	-416.789985
Other waste for treatment: waste water treatment	-206.214069
Food waste for treatment: waste water treatment	-182.413010
Electricity by solar photovoltaic	-82.979996
...	...
Cement, lime and plaster	19.494858
Furniture; other manufactured goods n.e.c. (36)	29.876384
Wood and products of wood and cork (except furniture); articles of straw and plaiting materials (20)	34.213711
Hotel and restaurant services (55)	92.412968
Electricity by coal	289.271157

(b) 2015-2030, carbon intensity (c)

sector	Mt CO2-eq
Cattle	-165.794622
Other waste for treatment: waste water treatment	-133.621262
Food waste for treatment: waste water treatment	-113.461105
Electricity by gas	-109.801786
Electricity by solar photovoltaic	-81.711938
...	...
Raw milk	103.284785
Electricity by coal	115.854627
Other Bituminous Coal	144.081178
Basic iron and steel and of ferro-alloys and first products thereof	144.522728
Paddy rice	151.413038

(c) 2015-2030, energy efficiency (e)

sector	Mt CO2-eq
Electricity by coal	-528.463128
Cement, lime and plaster	-10.072276
Natural Gas Liquids	-6.588995
Crude petroleum and services related to crude oil extraction, excluding surveying	-6.482175
Distribution and trade services of electricity	-5.814630
...	...
Electricity by wind	12.820918
Basic iron and steel and of ferro-alloys and first products thereof	15.168668
Electricity by gas	42.792353
Paddy rice	47.360041
Electricity by solar photovoltaic	89.389102

(d) 2015-2030, production recipe (**L**)

sector	Mt CO2-eq
Extra-territorial organizations and bodies	0.000000
Food waste for treatment: incineration	0.000000
Wood waste for treatment: incineration	0.000000
Textiles waste for treatment: incineration	0.000000
Other Hydrocarbons	0.000000
...	...
Cattle	154.699414
Cement, lime and plaster	170.019962
Other Bituminous Coal	181.937410
Paddy rice	192.550672
Electricity by coal	668.940458

(e) 2015-2030, demand volume (y)

Figure N1: Most significant contributors to emission changes, 2015-2030: CEA45%b [Mt CO_2e]

O Tables: SDA, electricity use, 2015-2030: CEA45%b

sector	TWh
Electricity by gas	-5.965067
Electricity by petroleum and other oil derivatives	-0.585991
Electricity by nuclear	66.932698
Electricity by biomass and waste	97.363355
Electricity by wind	131.338581
Electricity by hydro	151.373169
Electricity by coal	247.396891
Electricity by solar photovoltaic	273.690631

(a) 2015-2030, total

sector	TWh
Electricity by solar photovoltaic	-473.129390
Electricity by wind	-239.889036
Electricity by gas	-233.372064
Electricity by hydro	-64.970122
Electricity by petroleum and other oil derivatives	-9.304716
Electricity by nuclear	19.476855
Electricity by biomass and waste	41.272033
Electricity by coal	143.058477

(b) 2015-2030, energy efficiency (e)

sector	TWh
Electricity by coal	-652.360773
Electricity by nuclear	-4.368715
Electricity by petroleum and other oil derivatives	-1.076689
Electricity by biomass and waste	55.699912
Electricity by gas	90.924007
Electricity by hydro	101.624930
Electricity by wind	207.631787
Electricity by solar photovoltaic	517.430378

(c) 2015-2030, production recipe (**L**)

sector	TWh
Electricity by biomass and waste	0.374873
Electricity by petroleum and other oil derivatives	9.791111
Electricity by nuclear	51.795344
Electricity by hydro	114.647524
Electricity by gas	136.401249
Electricity by wind	163.484879
Electricity by solar photovoltaic	229.170814
Electricity by coal	756.324680

(d) 2015-2030, demand volume (y)

Figure O1: Most significant contributors to electricity use changes, 2015-2030: CEA45%b [TWh]

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