Global economic implications of the Nationally Determined Contributions of the Paris Agreement

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Abstract

The Paris Agreement is a major agreement by parties to the United Nations Framework Convention on Climate Change. It aims to limit increases in the average global temperature to 2℃ above the pre-industrial average, or 1.5℃ if possible. As part of the agreement, countries must periodically commit to greenhouse gas emissions reductions, known as Nationally Determined Contributions (NDCs). Countries will compare the effort required to achieve commitments they are considering with the effort required by other countries to achieve theirs. There are several ways that effort can be compared. There is often a focus on economic metrics and so a key question is, what are the economic consequences of the NDCs? This paper seeks to answer this question using computable general equilibrium (CGE) modelling.

GDyn-E is a recursive dynamic CGE model developed to assess the impacts of global climate change agreements. I extend the model in two ways to produce a quantitative assessment of the global economic impacts of the Paris Agreement. Firstly, I disaggregate the electricity sector in a manner like that in GTAP-E-Power, a comparative static CGE model. Secondly, I link the model to the Global Trade Analysis Project's non-CO_2 greenhouse gas database.

The database read by the model is updated to version 10 of the GTAP database. Key model parameters within the electricity sector are calibrated using observations in the period since 2014. Technological changes in the electricity sector are accounted for via productivity shocks.

NDCs submitted to the United Nations are interpreted to develop greenhouse gas emissions trajectories for the regions in the model. Differences between the results with and without emissions reductions are discussed. Finally, I consider the way that impacts on economic metrics vary between countries and how that can be interpreted to reflect the effort that each country is putting in to meeting the goals of the Paris Agreement.

1 Introduction

Climate change is likely the most important environmental issue of our time, with the potential to worsen existing pressures on many living things (Steffen et al., 2015). The Paris Agreement (United Nations Framework Convention on Climate Change, 2015) seeks to lower the emission of greenhouse gases in order to "reduce the risks and impacts of climate change". The OECD (2012) suggest that much of the increase in greenhouse gas emissions over recent decades has come from electricity generation, with the Intergovernmental Panel on Climate Change (2014) mentioning coal use specifically as the biggest cause of increased emissions from that sector.

Recognising this, Peters (2016b) disaggregated the electricity sector in the static GTAP model and used it to analyse the costs that some countries will incur to achieve their emissions reduction targets. However, countries' targets are not all proposed for the same year (Fenhann, 2020), so a static model is not capable of representing the ways that the emissions trajectories countries are proposing will interact over time. GDyn-E is a dynamic model that has been used in the past to estimate the economic impacts of global climate change agreements, most recently by Golub (2013). In this paper I update the database read by GDyn-E and disaggregate the electricity sector within it, then I disaggregate the electricity sector in the model to make use of the new data.

2 Data and methods

2.1 Database

Version 10 of the GTAP database for 2014 (Aguiar et al., 2019) was aggregated into the regions and sectors shown below. There are a number of headers in the GTAP database that are not read by either GDyn-E or GTAP-E-Power. No splits have been performed on headers not read in by either model. They are all various types of industry protection measures. Parameters for dynamics were produced by aggregating version 9 of the GDyn database (Golub, 2016).

Regions:

- China
- United States of America
- India
- Russia
- Japan
- The European Union (EU)
- Australia
- The rest of the Americas

- The rest of Asia and the Pacific
- The rest of Europe and the former Soviet Union
- The Middle East and Africa

Sectors:

- Primary production of plants
- Primary production of animals
- Coal mining
- Crude oil mining
- Gas extraction, manufacture and distribution
- Other mining
- Processed food, drinks and tobacco
- Refined oil products
- Energy intensive industries
- Electricity
- Water
- Transport
- Other industries
- Services

2.1.1 Electricity data

The electricity sector in the GTAP database was disaggregated into the sectors below. All disaggregation of GTAP data was undertaken using GEMPACK software (Horridge et al., 2018).

- Transmission and distribution
- Generation using one of the following technologies:
  - Coal
  - Oil
  - Oil products
  - Gas
  - Nuclear
  - Hydro
  - Wind
  - Solar
  - Other

Generation

With the exception of the wind, solar and "other" electricity generation technologies, data for has been extracted directly from the "Electricity and Heat Output" section of tables in IEA (2016a). Data for wind and solar was extracted from the "Summary Time Series" section of IEA (2016b). Those values were then subtracted from the values for "Geotherm./ Solar/ etc." in the "Electricity and Heat Output" section of tables in IEA (2016a), with the difference added to values for "Biofuels/ Waste" values in the "Electricity and Heat Output" section of tables in IEA (2016a) to produce the value for the "Other" electricity generating sector. These values are shown in Table 1.

Table 1: Electricity generation by source (MWh)

Region	Coal	Oil	Oil Pcts	Gas	Nuclear	Hydro	Wind	Solar	Other
China	4145.62	0.00	9.75	123.68	132.54	1051.14	156.08	29.23	57.62
USA	1712.58	0.00	39.88	1161.33	830.58	261.47	183.89	24.60	104.82
India	966.52	0.00	22.70	62.93	36.10	131.64	37.16	4.91	25.44
Russia	158.30	0.01	10.69	533.49	180.76	175.27	0.10	0.16	3.56
Japan	348.83	30.98	85.46	420.83	0.00	81.80	5.04	24.51	38.10
EU	739.40	0.00	53.37	352.65	812.54	366.69	221.14	93.73	171.67
Australia	151.85	0.00	5.01	54.39	0.00	18.39	10.25	4.86	3.51
Rest of the Americas	167.90	6.90	200.78	477.54	138.49	1122.17	47.51	3.03	165.23
Rest of Asia and the Pacific	425.32	0.00	108.32	521.57	47.48	210.00	5.17	2.63	43.87
Rest of Europe and rest of the former Soviet Union	412.10	0.00	11.12	398.64	209.70	360.46	52.54	8.35	39.85
Middle East and Africa	258.91	105.82	317.04	895.03	18.26	142.95	5.71	1.76	5.95

Sources: IEA (2016a), IEA (2016b) and author's calculations

Transmission and Distribution

The first step in disaggregating the electricity sector was to split expenditure on generation out from that on transmission and distribution. The shares going to transmission and distribution are shown in Table 2.

Table 2: Share of electricity costs assigned to transmission and distribution

Region	**Share**
China and Hong Kong	32%
USA	20%
EU	31%
India	31%
Russia	11%
Japan	28%
Australia	54%

Sources:

- China - He et al. (2015)
- USA - EIA (2019)
- EU - Eurostat (2020)
- India - Power Finance Corporation (2016)
- Russia - Summanen and Arminen (2018)
- Japan - Federation of Electric Power Companies of Japan (2020)
- Australia - Australian Competition and Consumer Commission (2018)

Other regions were assigned the weighted average of the shares above, which was 27%, with the weights being the total cost of electricity in each region.

Levelized Cost of Electricity

For the majority of generation technologies, capital and operating costs were sourced directly from IEA/NEA (2015). With the exception of costs for oil and oil products, global average costs, shown in Table 3, were calculated by weighting the costs reported in IEA/NEA (2015) by the capacity of the plant that they are associated with. In one case, hydropower, the costs reported for the lone Chinese plant were excluded due to its size and comparatively low capital cost.

Table 3: Global average levelized costs of electricity generation ($/MWh)

Technology	Capital	O&M	Fuel	Total
Hydro	$24.13	$9.73	$-	$33.85
Coal	$13.00	$7.77	$27.87	$48.64
Nuclear	$25.30	$14.17	$10.08	$49.55
Solar	$64.22	$24.77	$-	$88.99
Gas	$7.42	$5.55	$78.27	$91.23
Oil	$13.73	$24.40	$67.93	$106.06
Wind	$71.95	$38.21	$-	$110.16
Other	$12.17	$16.74	$96.03	$124.95
Oil Products	$33.01	$15.90	$242.00	$290.91

Sources: IEA/NEA (2015), IEA/NEA (2010), Lazard (2016) and author's calculations.

Unfortunately, IEA/NEA (2015) does not include cost projections for electricity generation from crude or refined oil. Data for the cost structure of electricity generation from oil products comes from the Power Generation Cost Analysis Working Group (2015) using the same exchange rate as in IEA/NEA (2015). The fuel component varies regionally based on the relationship to the cost in Japan in Lazard (2016). In regions not covered by Lazard (2016), the cost for the USA was used for major oil producing regions and the average value of the regions in Lazard (2016) was used otherwise. Data for the cost structure of electricity generation from oil comes from IEA/NEA (2010), by using ratios between the cost components for generation from oil and gas in the one region that had the cost structure for generation from oil reported in that publication. The assumption here is that, due to the relationship between gas and oil prices, the ratios will remain constant.

If IEA/NEA (2015) included no reports about the costs of any generating technology for a given region, that region was given average global costs for capital, as well as operation and maintenance. This applies for India, Russia and Australia. As the only technology that had costs reported for any of the countries in the "Rest of the Americas" region was hydro power in Brazil, average global costs of capital, as well as operation and maintenance, were used for all other technologies in that region. In all other regions, the cost assigned to any generation technology missing data was calculated by maintaining the ratio between the average global cost for that component to the average cost across all components.

Disaggregation

For the electricity sector, generally the use of all commodities was assigned to transmission and distribution according to the shares discussed shown in Table 2. The remainder was allocated to the specific generation sectors by cost share calculated by multiplying the sector output shown in Table 1 by a cost per megawatt hour for that sector in that region. The cost used depends on the generating technology. For most it was the cost of operation and maintenance. However, for the nuclear and “other” electricity sectors, the cost was the cost of operation and maintenance summed with the cost of fuel, due to difficulties in dealing with the cost of fuel for these sectors separately, which is discussed below. This same approach was applied to the use of all endowments other than capital. For capital, the cost of capital for each generation technology in each region was calculated by multiplying the sector output shown in Table 1 by the cost of capital per megawatt hour for that sector in that region. Those were then divided by the total cost across all generation technologies in each region, to get the share of capital expenditure to assign to each generation technology, in each region, after assigning the transmission and distribution sector its share.

The cost of electricity consumed by each sector was split across the different generation technologies by first calculating the total cost of generation incurred by each technology (excluding the cost of carbon). That was then divided by the the sum of total costs across all technologies to get the share of total generation to use of each generation technology. For splitting imports of electricity, the amount, at market prices, imported by each country from each country was divided up using the cost shares in the source country, then those were summed for each electricity commodity and those values then used to get the unique import electricity cost mix for each country.

Fuel commodities were approached differently. First the cost to the generator was calculated by multiplying the sector output shown in Table 1 by the fuel cost for that sector in that region. Then, after the relevant fraction was allocated to transmission and distribution, the remainder was distributed amongst other generation technologies that produce emissions. Those technologies were the four technologies generating electricity from fossil fuels, along with the “Other” category, as it produces emissions in many regions through consumption of biomass and biogas. Those same shares were used to split emissions from fuel use by the electricity sector in the GTAP database into emissions from the different generating technologies, as well as transmission and distribution.

The approach above for splitting fuel use by the electricity sector was considered for fuels for the nuclear and other generating technologies. However, in the case of nuclear, which sources its fuel from the Energy Intensive Industries, in many cases the cost of fuel calculated according to IEA sources was far greater than the total of imports and domestic production of Energy Intensive Industries. As for the “Other” electricity generating technologies, which source fuel from the forestry, lumber and water sectors, there was insufficient data to assign output of those sectors accurately.

At this point it is worth noting that the IEA electricity generation data, summarised in Table 1, is, in some regions, considerably different to the electricity consumption data in the GTAP database (Aguiar et al., 2019). Trade in electricity between regions was insufficient to account for the discrepancy. Consideration was given to using the consumption data to scale the generation data in order to produce a more balanced database. However, in most cases, database manipulation was undertaken using shares and so the mismatch is inconsequential. The only splits that used the generation data itself were for fuel use by the electricity sector. Upon inspection, scaling the IEA data was not necessarily going to result in a more realistic disaggregation of fuel use. Specifically, electricity use in Japan in the GTAP database was approximately 37% of electricity generation according to the IEA. Scaling down the IEA data to match the GTAP database would have resulted in considerably less use of oil products by the sector that generates electricity through the use of oil products, leaving the remainder to be distributed amongst other generating technologies. Conversely, the other two regions where large discrepancies were observed were the EU and Russia, which both produced significantly more electricity according to the IEA than they consumed according to the GTAP database. Whilst scaling up the IEA data would result in less fuel use to be redistributed amongst different generating technologies, the amount redistributed using the IEA numbers is less significant than the amount of oil products that would need to be redistributed in Japan if those numbers were to be scaled.

2.1.2 Global trust

Details about investments come from version 9 of the GDyn database (Golub, 2016). As the base year of that database is 2011, those values needed to be scaled to use in the base year of version 10 of the GTAP database, 2014. Of importance is that the trust's income must be equal to the amount that it pays regional households that invest in it. Therefore, the income earned by the trust in each region has been adjusted for inflation (U.S. Bureau of Labor Statistics, 2020) then scaled up according to the change in firm output in that region. The income of the household in each region from the trust has then been adjusted for inflation, then the difference between that and the income earned by the trust from the firms has been split amongst the regions according to their share of total savings. The income of the household on equity in the local firm has been scaled up by inflation and then by the change in firm output.

2.1.3 Non-CO_2 greenhouse gases

The source of data regarding emissions of greenhouse gases other than carbon dioxide is Ahmed et al. (2014). I divided the emissions of each gas by the output or input, as relevant, from the corresponding version (8) of the GTAP database (Narayanan, G. et al., 2012) for each sector and region to get the emissions intensity of each coefficient. In two regions, there was a sector (a different sector in each of the two regions) that had a significantly higher emissions intensity than the same sector in other regions. For those, global average values were used. Emissions intensities were then multiplied by the relevant coefficient from version 10 of the GTAP database to estimate emissions in 2014. The assumption here is that there has been no change in emissions intensity between 2007 and 2014, which was made due to a lack of access to the latest version of the non-CO_2 database at the time the work was done. The only emissions of non-CO_2 gases from the electricity sector associated with output were of fluoride gases. These were allocated to transmission and distribution.

2.1.4 Parameters

Most parameters have come either directly from the GDyn database (Golub, 2016) or, in the case of the parameters specific to the alternative method of modelling energy use in GDyn-E, from Golub (2013). There are some exceptions, outlined below.

Values for the substitution parameter controlling the ability to substitute between factor inputs and the capital-energy composite, known as "ELFVAEN" in the model, have, for the most part, come from Golub (2013), with sector output used as a weight where necessary. Values for the "Services" and "Other Industries" sectors come from Burniaux and Truong (2002). Some adjustments were necessary to facilitate modelling of non-CO_2 greenhouse gases: the value for gas in China needed to be reduced very slightly to 0.052. The value for coal in Japan needed to be reduced significantly to 0.2.

As in Peters (2016b), electricity generating technologies that need increases in capital to increase generation had their parameters for substitution between factor inputs, as well as between capital and energy ("ELFKEN" in the model), set to zero. They are nuclear, hydro, solar and wind generating technologies. "ELFKEN" values were set to 0.1 for the "Other electricity" generation sector and 1 for generation sectors that consume fossil fuels, except for coal, following Peters (2016b).

The substitution parameter governing the ease that electricity generation by one method can be substituted for another comes from Peters (2016b). However, because electricity generation has not been split into base and peak load technologies, a weighted average of the parameters used by Peters (2016b) was taken. Weights were taken from the shares of global electricity generation from different technologies in Peters (2016a).

The value for the parameter for rigidity of allocation of wealth by the regional household ("RIGWQH") was increased from 0.01 to 0.02 for two regions: India and China. This was necessary to avoid negative values in investments in the global trust.

Two other changes to parameters were necessary to prevent negative values in simulations where non-CO_2 greenhouse gases were shocked. The Armington elasticity for substituting between domestic products and imports ("ESUBD") of gas was reduced slightly to 12.19. Finally, the elasticity of transformation between sectors ("ETRAE") for natural resources had to be increased significantly to 0.2.

2.2 Model

The starting point for the model was the model used by Golub (2013). I have edited the model code to include changes made by Peters (2016b) to the GTAP-E model code, modified slightly to combine the base and peak electricity generation nests into a single generation nest. This is warranted as there is evidence to suggest that it is possible for renewable technologies to generate sufficient electricity for the economy. See for example a report on the matter by the Australian Energy Market Operator (2013). The model was updated to include emissions of greenhouse gases along the lines of Brinsmead et al. (2019). Some minor changes were also required to address divide by zero errors and singular matrices. Note that I use the "alternative savings" closure discussed by Golub (2013).

2.3 Exogenous variables

Growth in population, skilled and unskilled labour were taken from Golub (2013) using populations from 2014 according to the GTAP database (Aguiar et al., 2019) as weights. Technological change was also taken from Golub (2013), with GDPs from 2014 according to the GTAP database used as weights. Emissions to date and proposed as Nationally Determined Contributions are based on Fenhann (2020). The shocks applied to the model to represent the Nationally Determined Contributions are shown in Table 4. Where countries have submitted a range of emissions (such as a target contingent on actions taken by other countries, along with a non-contingent target), the upper end of that range has been used. "Sectoral goals" and reductions compared to future baseline emissions, when those baseline emissions levels have not been submitted, have been ignored.

Table 4: Annual percentage changes in emissions quotas

Region	**2020-2025**	**2025-2030**
China and Hong Kong	0.6	0.6
United States	-2.3	0.0
European Union	-3.3	-3.3
India	2.0	2.0
Russia	1.9	1.9
Japan	-2.2	-2.2
Australia	-1.5	-1.5
Middle East and Africa	1.3	1.4
Rest of Asia and the Pacific	2.3	2.9
Rest of the Americas	-0.4	0.3
Rest of Europe and former Soviet Union	1.0	0.7

Sources: Fenhann (2020) and author's calculations.

Finally, the decline in cost of generating electricity from wind and solar technologies documented in Frankfurt School - United Nations Environment Programme Centre and Bloomberg New Energy Finance (2018) has been roughly reproduced by shocking the technological change variable ("afsec") for those sectors during the historical period. The values used were an annual improvement of 4% per year for solar and 1% per year for wind.

3 Results

At a global scale, the impact on world output (i.e. the sum of Gross Domestic Product, or GDP, across all regions) in real terms was minimal, being just 0.4% lower in 2030 due to the policy, which is summarised in Table 4. Lower GDP, in the policy simulations compared to the base case, in real terms, in Russia, the rest of the Americas, the Middle East and Africa is almost fully offset by increases in the other regions.

Due to the potential for revenue from emissions taxes to be redistributed or to improve public services, impacts on the citizens of each region are possibly best understood by comparing the sum of public and private consumption in real terms. Such a comparison is presented in graphical form for selected regions in Figure 1.

Figure 1: Cumulative deviation in real aggregate consumption (%)

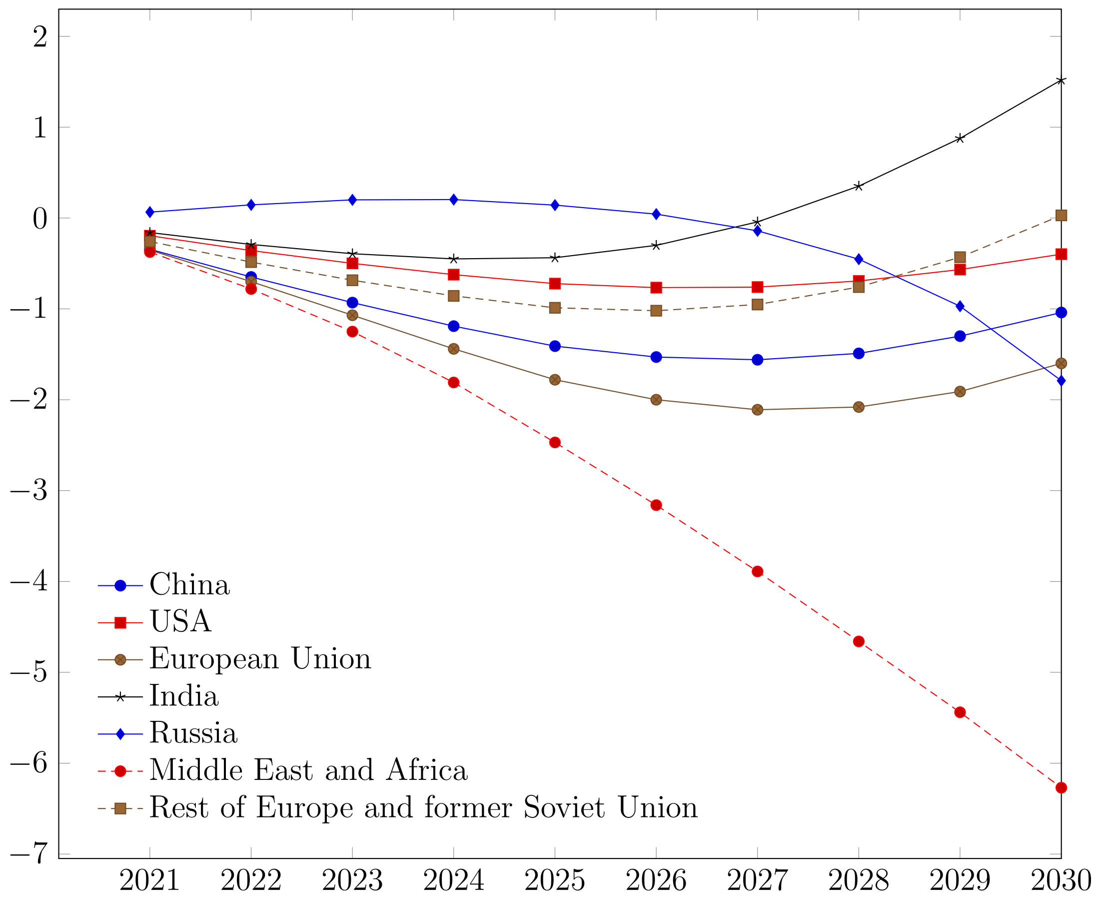
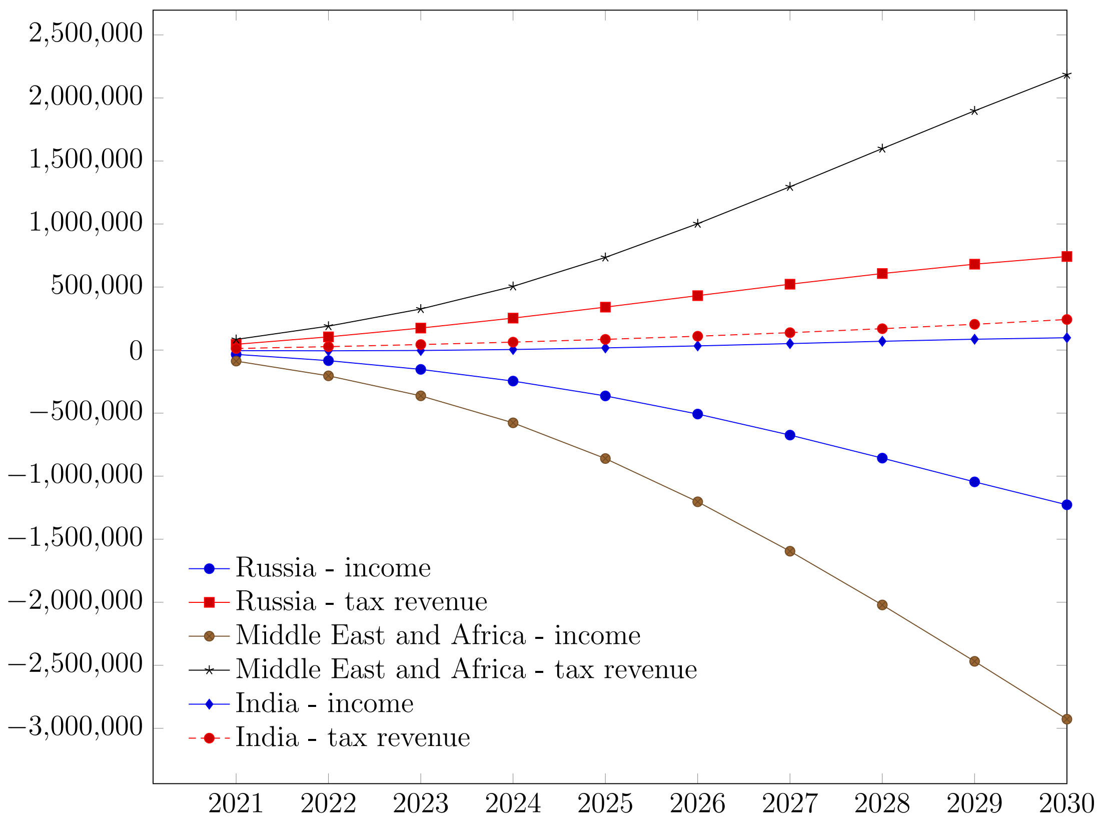


Figure 2 shows changes to sources of income for the two hardest hit regions and the region that most benefits from the Agreement.

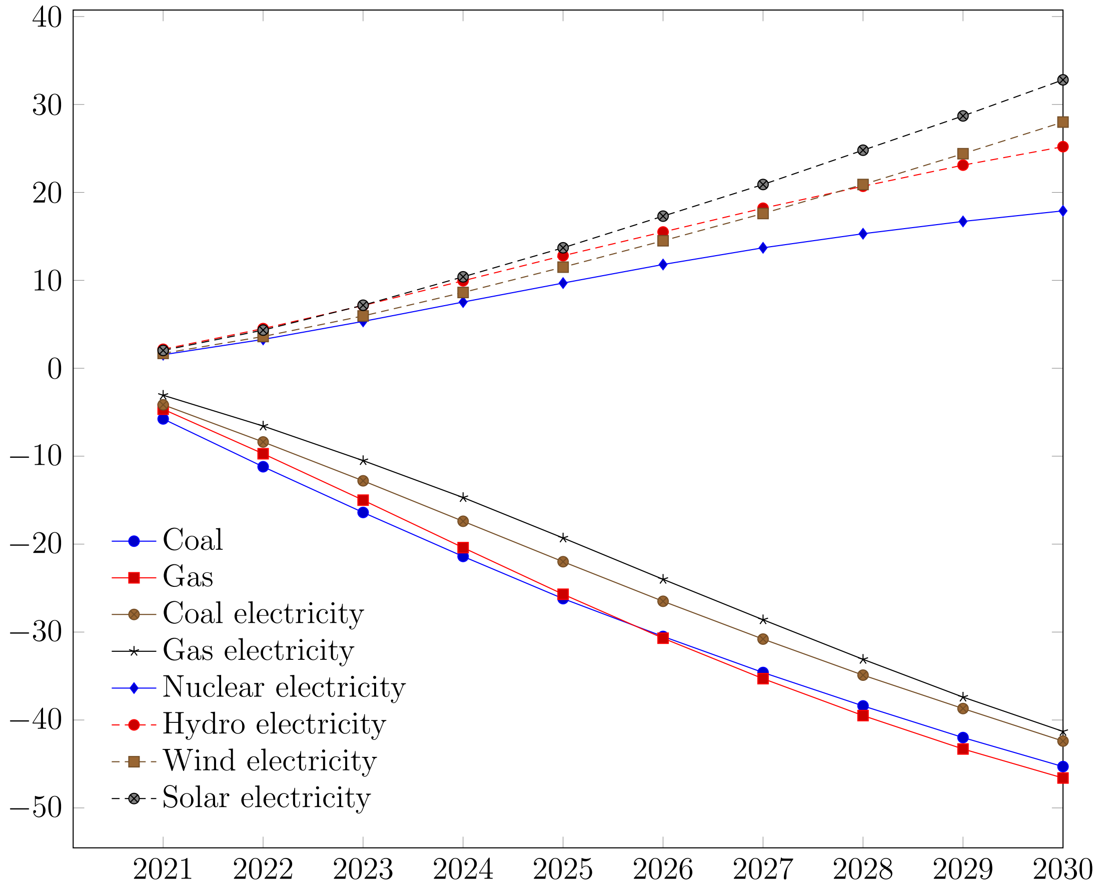
Figure 2: Change in income and tax revenue (2014 USD, millions)



The reason for the decline in income for Russia, the Middle East and Africa is straightforward - their heavy reliance on fossil fuel exports. In India the major changes in sectoral response to the Agreement are the same as those globally (discussed next), though there are some smaller changes that are different to those seen globally. As the region with the greatest increase in emissions over the period modelled here, they see a slight increase in some industries that reduce output elsewhere as part of emissions mitigation efforts. This is especially the case with oil products. A global reduction in demand for oil reduces its price, which is a major input for the oil products sector. Consequently, the oil products sector in India grows, as do two of the sectors heavily reliant on it - transport and electricity generation from oil products. That these sectors in India grow by more with the Agreement than they do without it shows the importance of the relative nature of emissions reduction targets. Though emissions grow by less in India than they would without the Agreement, they still grow by more than they do elsewhere in the world, making India more attractive to emissions intensive industries. It may not require much more "effort", at least when measured by the economic metrics discussed above, to achieve more significant reductions below "business as usual".

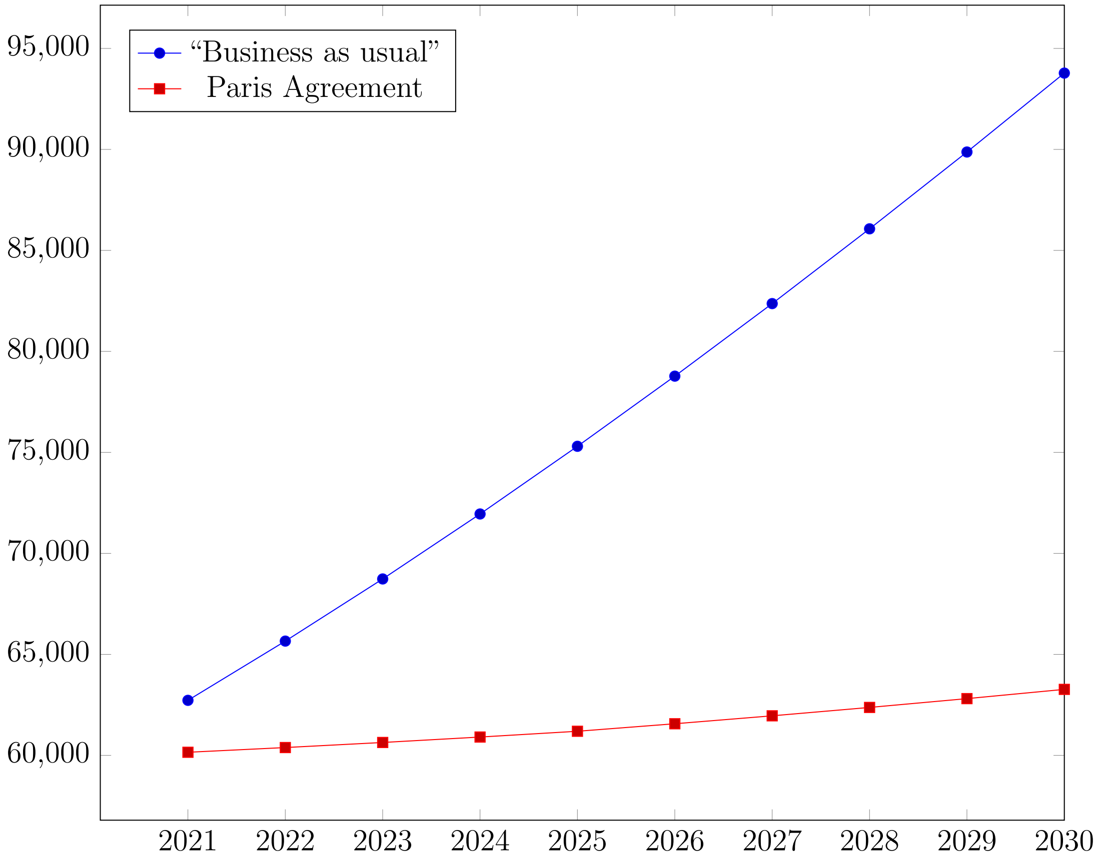
Figure 3 shows the change in output globally by the sectors that benefit and suffer the most due to the Agreement.

Figure 3: Cumulative deviation in global sector output (percent)



Finally, the success of the Agreement can be judged by the reduction in emissions shown in Figure 4.

Figure 4: Global greenhouse gas emissions (megatonnes CO_2 equiv.)



Here reductions in carbon dioxide emissions from the electricity sector are more than offset by increases in emissions of methane and nitrous oxide from agriculture, as well as, to a lesser extent, fluorinated gases from industry.

4 Next steps

Further work on the model baseline is necessary. As the base year is 2014, simulations need to be undertaken to update the data. Historical GDP growth will be taken from the International Monetary Fund (2019). Parameters and technological growth may need to be adjusted for the electricity sector. The model should be able to reproduce changes to the sector observed in publications such as IEA (2019a) and IEA (2019b). The agricultural sectors might need to be disaggregated in order to allow substitution away from more emissions intensive agriculture. In general, trends in the emissions intensity of the most sectors other than electricity need to be incorporated into the modelling.

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