United States Re-enters the 2015 Paris Climate Agreement: The Unexpected Twists and the Opportunity Costs? A CGE Approach[1]

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Abstract

With renewed GHG emission reduction commitments and the rejoining of the Paris Climate Agreement of 2015 by the USA, this study attempts to examine the global economic implications of carbon emission reduction targets, including the opportunity cost the USA is likely to pay to implement its nationally determined commitments (NDC). The analysis employs the GTAP-E model and the GTAP database version 10 with a base year of 2014. Counter virtual experiments include eight simulation scenarios; however, we focus on scenarios 3 and 4, which evaluate global emission reduction with trading excluding and including the USA. Simulation results suggest that worldwide CO_2 *emission trading significantly lowers the cost of implementing* CO_2 *emission reduction relative to the global* CO_2 *emission reduction under the no use of flexibility mechanism experiment. Besides, if the USA implements its NDC as intended in scenario 4, USA's GDP will contract by 0.14%, while its welfare will contract by $74.24 billion. However, if the USA does not implement its NDC as in scenario 3, its GDP will contract by 0.07%, while its welfare will contract by $4.46 billion. Consequently, the USA's opportunity cost of* CO_2 *emission reduction will be in the form of a decline in domestic output of 38.07% and 5.71% in coal, and the related contraction of 6.87% and 1.61% in oil, 61.23% and 9.62% in gas, 17.41% and 1.88% in oil products, 20.39%, and 2.92% in electricity, and 10.35% and o.37% in transport services, under* CO_2 *emission reduction with no use of flexibility mechanism and emission trading experiments, respectively.*

Keywords: Climate Change, GTAP-E Model, NDC, Paris Climate Agreement, Social Cost of Carbon, USA

JEL Classifications: C68, C83 D31, O15

I. Introduction

The reduction of greenhouse gas (GHG) emissions has a broad spectrum of benefits to the natural ecosystem, economic growth, and global climatic conditions. However, meeting the intended nationally determined contribution (NDC) greenhouse gas (GHG) reduction targets requires significant economic structural changes, which contribute to the NDC implementation costs (Chepeliev, Osorio Rodarte, and van der Mensbrugghe, 2021). Therefore, achieving a livable climatic environment by reducing greenhouse gas (GHG) emissions to net-zero (0) by 2050, as envisioned within the UNFCC frameworks that include the Paris climate Agreement and the Conference of Parties 26 (COP26), requires a shared approach. Notwithstanding, even though there is considerable uncertainty about the magnitude of the social cost of CO_2 emissions (Wolverton, Kopits, Moore, Marten, Newbold, and Griffiths, 2012; IMF, 2012; and Rennert et al., 2021), especially CO_2, it is general knowledge that CO_2 has a profound negative impact on

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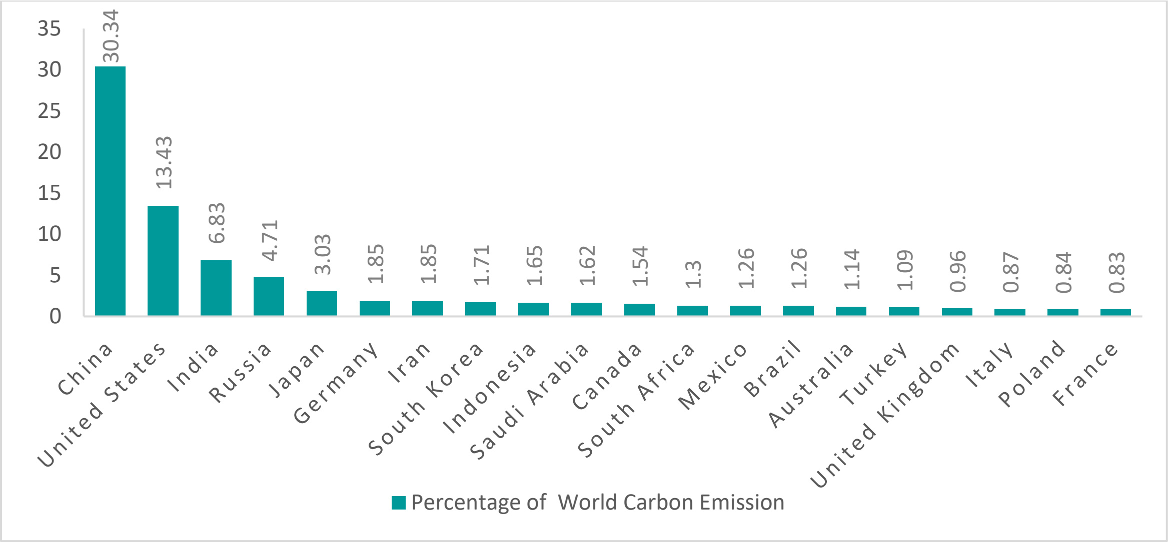
the environment and human and animal health which affects economic productivity. Yet, the trajectory of the development of global climatic conditions suggests that the future existence of humanity is pegged upon the appropriateness of the current decisions to address climate change and the accompanying actions to build a sustainable world. The recommitment of the United States of America (a major GHG emitter) to the Paris climate agreement will provide a new lifeline to the global GHG emission reduction, which is likely to generate significant economic impacts globally (Syed and Ullah, 2021).

Furthermore, there is deepening concern that the rise in the atmospheric concentration of greenhouse gases (GHG) resulting from the use of fossil fuels are at their highest levels in 2 million years, and their emission continues to rise. Consequently, the earth is now approximately 1.1°C warmer than in the late 19th century. Unsurprisingly, available records indicate that the last decade (2011-2020) was the warmest since the late 1800 (IPCC, 2018, 2022; IEA, 2021). Improved climate analysis methods using archived, observed current data have placed human activities at the center of the upsurge in GHG concentrations since 1750. In short human activities have led to Observed increases in well-mixed GHG concentrations since around 1750 (as reported in the IPCC AR5 report) to about 410 ppm for CO_2, 1866 ppb for methane (CH4), and 332 ppb for nitrous oxide (N2O) in 2019. At the same time, the global CO_2 emissions by land and the sea resulting from human activities stood at 56% per annum for six decades (IPCC, 2021). In order to mitigate or adapt to the enormous implications of climate change, collaborative efforts (political, financial, and scientific) from all stakeholders are necessary prerequisites. In addition, evolving global events have shown that political goodwill plays a crucial role in national climate policy formulation, especially the provision of funds needed to implement climate mitigation and adaptation programs nationally and globally. Global efforts to address concerns of the increasing atmospheric concentrations of the greenhouse gases (GHG) resulting from the enhanced natural greenhouse effect include the formation of the United Nations Framework Convention on Climate Change (UN,1992), the Kyoto Protocol (Protocol, 1997), the 2015 Paris Climate Agreement, and the Conference of the Parties (UNCC, 2021).

In an unpreceded move, on November 4, 2020, the United States of America (USA), under President Donald Trump, became the first and the only country to exit the Paris Climate Agreement, the 2015 landmark commitment by most countries to curb greenhouse gas emissions to keep global warming in check. However, in a twist of events, immediately after taking the oath of office, the current United States of America (USA) President Joe Biden (White House, 2021) signed an executive order commencing a 30-day process to rejoin the Paris Agreement on climate change. On Friday, February 19, 2021, the United States officially rejoined the Paris Agreement on climate change designed to limit global warming and avoid its potentially catastrophic impacts (Mai, H. J., February 19, 2021; Blinken, A. J., February 19, 2021), and submitted long-term low GHG INDC development strategy on November 1, 2021(Fenhann, 2022). The United States of America is the second top emitter of GHGs after China, accounting for 13.43%, while China accounted for 30.34% of carbon emissions in 2015. India ranked third, contributing 6.38%, followed by Russia (rank 4) at 4.71%, Japan (rank 5) at 3.03%, South Korea (rank 8) at 1.71%, South Africa (rank 12) at 1.30%, and the United Kingdom (rank 15) at 0.96%. Consequently, the re-entry of the USA to the Paris climate agreement and its commitment to GHG emission reduction is bound to have significant global economy-wide impacts. In this regard, the focus of this study is to empirically quantify the opportunity cost of the United States of America's re-entry into the 2015 Paris climate agreement and the effects of Carbon dioxide emission trading by China, the United States of America (USA), the European Union (EU27), the United Kingdom (UK), Japan, and Korea, by implementing climate policies based on NDC GHG reduction targets by all regions up to 2030.

Figure 1. World CO_2 Emission in 2015 (in Percent)



Sources: World Population Review (November 23, 2022) https://worldpopulationreview.com/country-rankings/CO_2-emissions-by-country

The effects of global climate change have begun to manifest through global phenomena on the ecosystem and agriculture, changes in precipitation, the rise in temperature, drought and heatwaves, intensity, frequency, and duration of hurricanes, and rise in sea level (by 1-8 feet in 2100), and the loss of snow in the arctic, mountains, lakes and rivers (IPCC, 2007; 2013). Unfortunately, these effects of human-caused global warming are happening now and are irreversible on the timescale of people alive today and are likely to worsen in the decades to come. Against this backdrop, there is an urgent need to provide up-to-date information on the actual cost (social cost of carbon) of greenhouse gases on the environment and society. The social cost of carbon is an estimate of the equivalent economic losses from emitting one additional ton of carbon dioxide into the atmosphere and thus the benefits of reducing emissions. Currently the interim social cost of CO_2 applied by the Inter-Agency Working group (IAWP) is US$51/Mtoe. However, new research grappling with uncertainty around climate change finds that the social cost of carbon is likely higher than previously estimated, especially if appropriate weight is factored in when evaluating future impacts of CO_2 emission (Rennert et al., 2021).

It is worth noting that the development of climate change mitigation policies by many state stakeholders has been sluggish, inefficient, and somewhat uncoordinated. The inability to lay strong mitigation policies seems to be primarily strategic and may be aided by economic and political concerns, lack of incentives, and the steady increase of state free-riders who form part of the bottlenecks in developing appropriate climate change mitigation policies. Accordingly, de Coninck et al. (2018) and Otto, Frame, Otto, and Allen (2015) suggest redesigning climate mitigation policies in a way that neutralizes and withstands economic and political drawbacks and the ability to overcome the exogenous pushback resulting from economic (Wolverton, Kopits, Moore, Marten, Newbold, and Griffiths, 2012) structural changes and political impediments.

A raft of measures focusing on mitigation, adaptation, finance, and collaboration, which aim at limiting the rise in global temperature to 1.5C, were agreed upon during the COP26 conference held in Glasgow, the United Kingdom (UK), from the 31st October to 12th November 2021, under what is now known as the Glasgow Climate Pact. The COP26 pact secured near-global net-zero GHG emission reduction targets with new NDCs commitments from 153, accounting for over 90% of world GDP. As a result of concerted efforts, a boost in addressing adaptation and loss and damage through the Glasgow - Sharm el-Sheikh Work Programme covering 80 countries, consolidated financial support from developed countries, romped in five public finance institutions to stop international support for the unabated fossil fuel energy sector in 2022. Other achievements in support of climate mitigation efforts include an undertaking by private financial institutions and central banks to realign their financial policies towards global net-zero through the consolidation of collaborative efforts between governments, businesses, and civil society on the delivery of climate goals faster. Finally, to ensure unified efforts, the establishment of collaborative councils and dialogues in energy, electric vehicles, shipping, and commodities and the streamlining of the Paris Rulebook - agreeing on the 'enhanced transparency framework' (standard reporting of emissions and support), a new mechanism and standards for international carbon markets, and set timeframes for emissions reductions targets were actualized (UNFCC, 2021).

There is adequate evidence supporting CO_2 emission trading capacity to reduce the marginal abatement cost of CO_2 emission reduction. However, in most instances, the impact of emission trading is not adequate to neutralize the effects of CO_2 emission reduction. Currently, most studies suggest investment in energy-efficient systems due to their broad spectrum of benefits, including lowering the cost of and demand for energy, ultimately reducing the overall production costs. Additional benefits of energy-efficient systems include improved air quality and environmental benefits from energy demand, extraction, and use. Furthermore, reduced energy demand lowers greenhouse gas emissions, a crucial contribution to climate change (Erbach, 2015; IEA, 2014).

Against this background, the USA government submitted a second NDC roadmap to reduce GHG emissions on April 22, 2021, and a long-term low GHG development strategy on November 1, 2021 (Fenhann, 2022). A review of existing literature identifies numerous studies evaluating the potential impact of the reduction of CO_2 emissions by the USA on its economy, which include Böhringer and Rutherford, 2017; Lee, Chang, and Lee, 2013; Jenkins, 2014; van de Ven, Westphal, González-Eguino, Gambhir, Peters, Sognnaes, et al., 2021). Significantly, the model and data applied in these studies, including regional and sectoral aggregation, are different from those employed in this study. Furthermore, the assumptions on reduction targets of CO_2 emissions made by Jenkins (2014); Lee, Chang, and Lee (2013); Böhringer and Rutherford (2017) are significantly different from those made in this paper. In line with the above context, this study aims to empirically quantify the potential economic impacts of GHG emissions reduction using the GTAP-E multi-region, multi-sector static computable general equilibrium (CGE) model.

This study provides crucial insights into the global contribution of the USA in the reduction of GHG emissions using current NDC emission targets. However, the main contribution is the opportunity costs the USA is likely to pay for implementing the current NDC emission reduction targets. In particular, simulation results indicate that the opportunity costs for the United States of America (USA) re-entry into the 2015 Paris climate agreement vary with region. Moreover, additional estimations to account for the effects of CO_2 emission reduction by the USA to third parties are applied. USA's opportunity cost of CO_2 emission reduction will be in the form of a decline in domestic output of 15.18% and 20.97% in coal, and the related contraction of 2.81% and 4.09% in oil, 24.39% and 34.44% in gas, 2.18% and 3.61% in oil products, 5.35 % and 7.98% in electricity, 0.90% and 1.21% in transport services. The opportunity cost the USA is expected to pay sharply increases if we compare the worldwide CO_2 emission reduction with no use of flexibility mechanisms i.e., emission trading (ET) or joint investments (JI) scenario 1(Sc1), and with emission trading scenario 4(Sc4).

This paper is structured as follows, after the introduction: Section II describes the CGE model applied in this study. Section III examines data and simulation procedures applied. Simulation results are discussed in Section IV, while Section V presents concluding remarks.

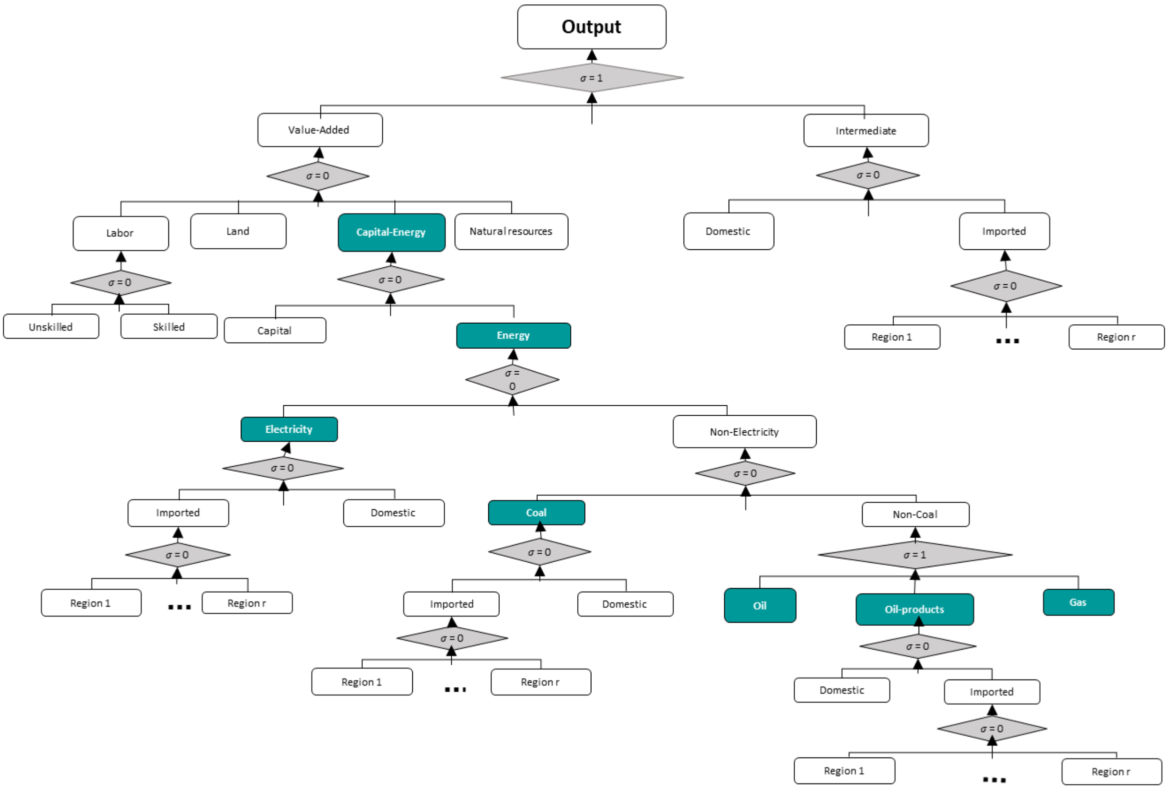
II. The GTAP-E CGE Model

In order to quantify the global economy-wide implications of carbon emission reduction targets, including the opportunity cost the USA has to pay for implementing its NDC emissions reduction targets under the Paris climate agreement of 2015, we employ a multi-region, multi-sector GTAP-E model, an extension of the standard GTAP model (Burniaux & Truong, 2002; Hertel 1997). The theoretical framework of the GTAP-E model introduces inter-fuel and energy-capital substitution in production, carbon dioxide emission accounting, carbon taxation, and emission trading. The GTAP-E model analyzes energy and environmental-related policy issues (Burniaux & Truong, 2002). Therefore, one of the outstanding features of the model is the utilization of inter-fuel and inter-factor substitution in the production structure of firms and the consumption and expenditure behavior of the private household and the government.

The CGE model analyzes the economy as a whole and follows Leon Walras's general equilibrium theory, which holds that all economies can attain equilibrium where demand and supply for all commodities equilibrate and endowment factors at a set of relative prices. CGE models constitute non-linear simultaneous equations formulated based on existing economic theories. The numerical models combine economic theory and actual economic data to computationally evaluate the impacts of policies or structural changes while still accounting for interdependence and feedback of sectors in the economy. The numerical models describe the constrained optimizing behavior of economic agents such as the savers, investors, producers, exporters, importers, consumers, and the government (Ko, Jong-Hwan, 1993). The GTAP-E model structure is able to empirically review the impacts of climatic change, environmental policies or other external shocks, including the resultant efficiency in resource re-allocation within an economy.

The production structure of the model allows each sector to produce one commodity using inputs from the value-added and the intermediate nests based on the prevailing production technology. The model applies the Cobb-Douglas utility (CES) functional form Corong et al. (2017); and Hertel (1997). The value-added nest comprises several primary factors of production: unskilled labor, skilled labor, land and natural resources, and a Capital-energy nest. Nevertheless, unlike other endowment factors of production, land is assumed to be immobile and therefore less substitutable for other primary factors in the production process in the standard GTAP model. Notwithstanding, the GTAP-E model identifies land as a significant input in the agricultural production process while still introducing energy as an additional input in the value-added composite (Burniaux and Truong, 2002).[4]

Figure 2. GTAP-E Capital-Energy Production Structure



Source: Authors' drawing based on Burniaux and Truong (2002)

Figure 1 illustrates the production structure of the GTAP-E model. Producers are assumed to lower production costs under a technology constraint at each production stage. Extension of the standard GTAP model involves relocating the energy commodities from the intermediate input nest and incorporating them into the value-added nest. The incorporation of energy into the value-added nest is a two-step process. First, energy commodities are broken into electricity and non-electricity composites. Some degree of substitution is allowed through a CES structure between the electricity and the non-electricity composite as well as within the non-electricity composite (Babiker, Maskus, and Rutherford, 1997; Burniaux and Truong, 2002). Next, the energy composite is then combined with capital to produce an energy-capital composite, which is in turn combined with other primary factors of production in a value-added-energy composite nest through a CES structure. The elasticity of substitution between capital and

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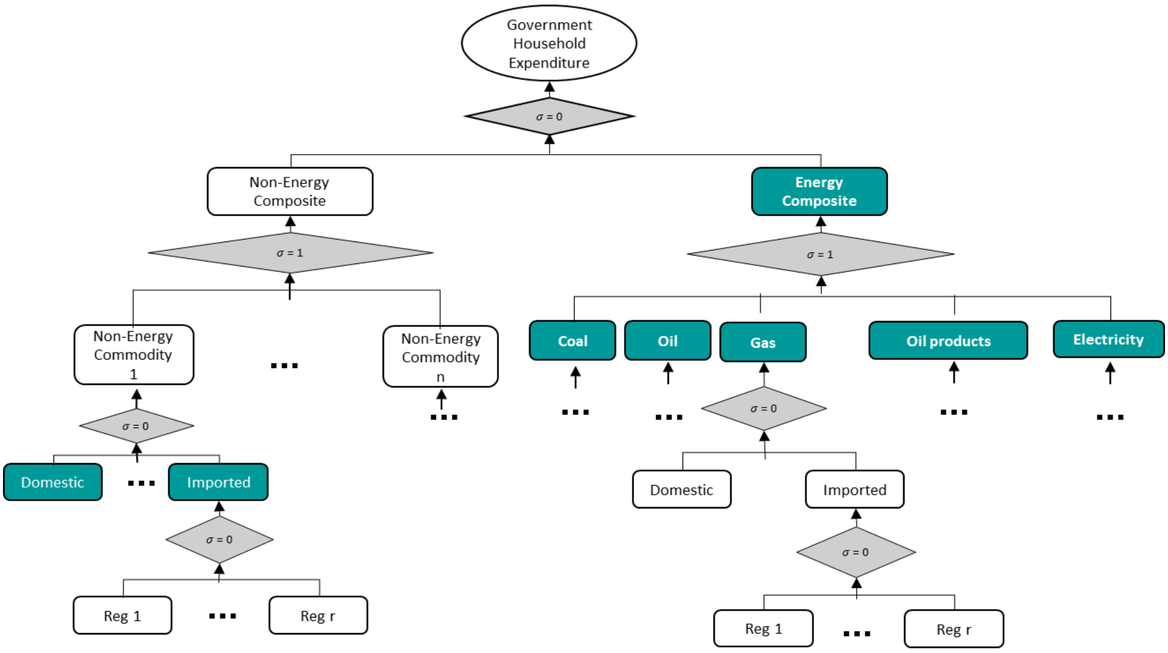
[4] The energy sectors: Coal, Oil, Gas, Oil products and Electricity are assumed to increase CO_2 emissions from the use of fossil fuels. The mechanization of the agricultural sector and the release of CO_2 during land reclamation and release of methane from animal wasted means that agricultural production, and climate change are intricately linked.

the energy composite is assumed to be positive, which implies that capital and energy are substitutes in the inner nest.

The GTAP-E model production structure is organized into eight levels, as shown in Figure 2. At the top level, the value-added composite with intermediate composite merged to produce industry output using a Cobb-Douglas production function. At the second level, the value-added composite is a CES aggregation of the capital-energy composite and primary factor composites. However, the intermediate composite is aggregated using the Armington elasticities (Armington, 1969) and likewise regarding substitution between domestically produced intermediate and imported intermediate inputs. At the third level, labor is a CES aggregation of skilled labor and unskilled labor, with the capital-energy composite being a CES aggregation of capital and the energy composite.

Figure 3. GTAP-E Government Purchases

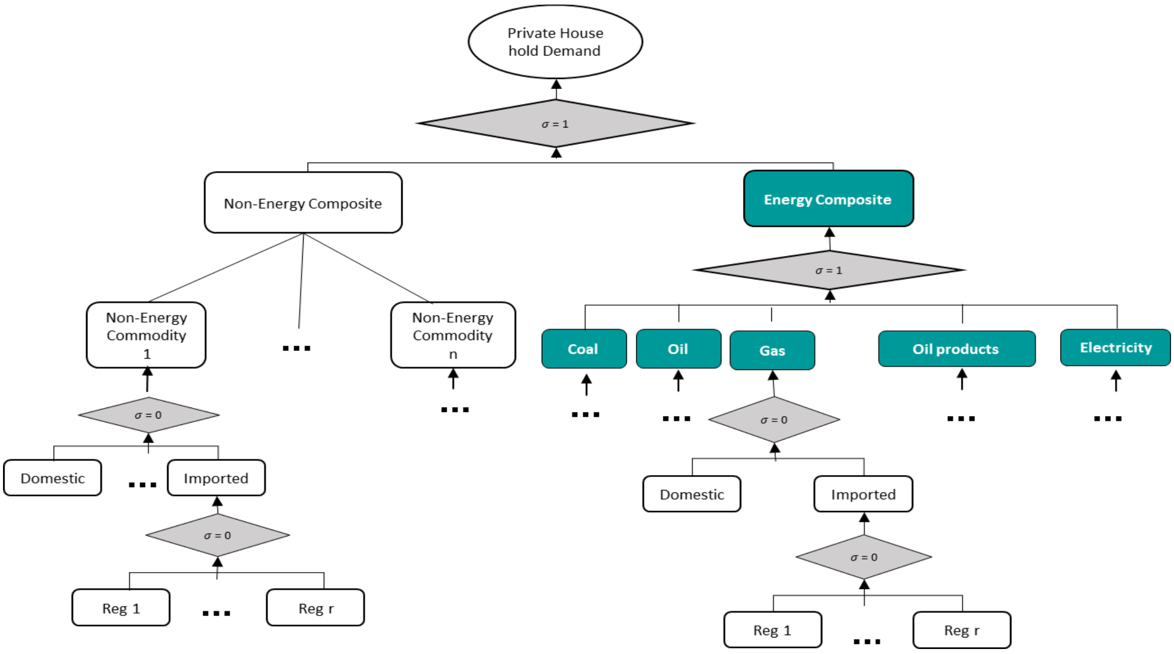


Source: Author’s drawing based on Burniaux and Truong (2002)

The demand side of the CGE structure is accounted for through private household consumption, government expenditure, and savings which is a proxy for investment. However, the demand for each of the three components of final demand is structured differently. As illustrated in Figure 3, government expenditure presumes a Cobb-Douglas consumption structure where both energy and non-energy commodities are aggregated through a CES functional form. However, domestically produced and imported non-energy goods are aggregated using a CES structure, with the imported non-energy goods aggregated following the Armington structure for all regions together to form the non-energy composite. Notwithstanding, the GTAP-E model's flexibility enables the provision of numerous substitution elasticities between energy and non-energy commodities. It is worth noting that the input construct of the energy nest for government consumption is similar to that of the private household.

In the standard GTAP model, consumer behavior with respect to the private household is addressed separately from the two other factors of final demand which include government expenditure and private

Figure 4. GTAP-E Private Household Purchases



Source: Author's drawing based on Burniaux and Truong (2002)

savings. As shown in Figure 4, consumption by the private household is assumed to be of a constant difference elasticity (CDE) form with references to all energy composite and non-energy products. Based on the GTAP-E structure four energy commodities; Coal, oil, gas, and electricity share the same parameter values (refer to Figure 4). This makes it possible to aggregate the energy commodities into one set with similar CDE parameter values of an individual energy commodity. It is also possible to establish a flexible substitution mechanism between energy goods, where the composite energy commodity should be specified as a CES sub-structure (Babiker, Maskus, and Rutherford, 1997).

III. Data and Simulation Procedures

3.1 Data

In order to examine the potential economic effects and the opportunity costs of CO_2 emission reduction by the USA and the rest of the world, this study applies the GTAP-E model, an energy-environmental extension of the standard GTAP model based on the GTAP database (DB) version 10 with a base year of 2014[5]. Extensions to the parameter file include substitution in production, consumption, and emission trading, while extensions to the data file cover carbon dioxide emissions, emission quotas, and carbon taxation. The GTAP-E DB contains data on 141 regions in 65 sectors (Aguiar, Chepeliev, Corong, McDougall, and van der Mensbrugghe, 2019). However, for analytical convenience and the focus of this study, the database is aggregated into 18 regions and 14 sectors, as indicated in Table 1.

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[5] https://www.gtap.agecon.purdue.edu/databases/v10/

Table 1. Regional and Sectoral Aggregation (Coverage)

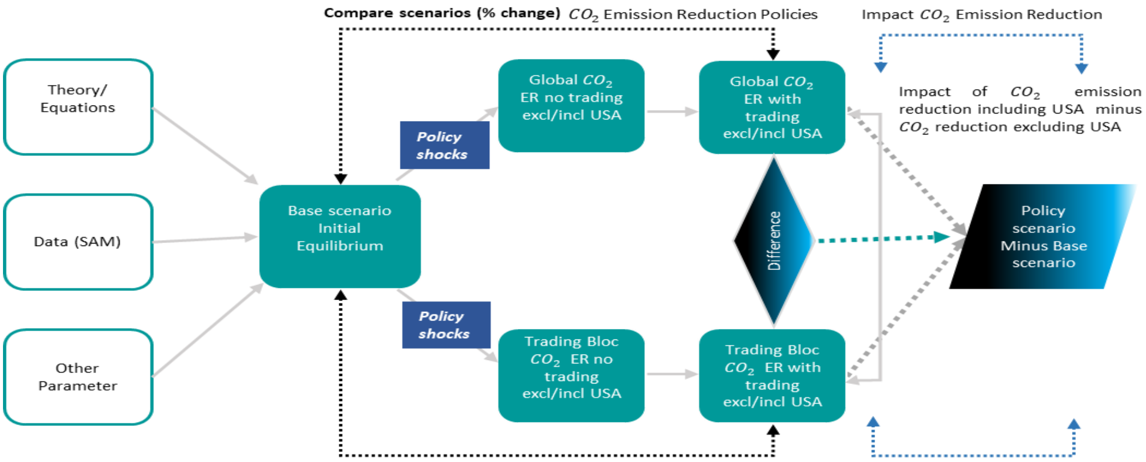
No.	Region	Description	Sector	Description
1	KOR	Korea South	Agr	Primary Agriculture
2	JPN	Japan	F_F	Forest and fishing
3	CHN	China	Coal	Coal mining
4	USA	United States of America	Oil	Crude Oil
5	UK	United Kingdom	Gas	Natural gas extraction
6	SAF	South Africa	Oil_pcts	Refined oil products
7	KEN	Kenya	PrcFood	Processed food
8	RWA	Rwanda	En_Int_Ind	Energy intensive industries
9	TZA	Tanzania	TMV	Transport Motor Vehicles
10	UGA	Uganda	Oth_Ind	Other industries
11	ETH	Ethiopia	Electricity	Electricity
12	FSU	Former Soviet Union	Construct	Construction only
13	OIC	Other industrialized countries	TransportS	Transport Services
14	OEX	Oil exporters	OthSvcs	Other Services
15	EU27	European Union 27		
16	NAF	Northern Africa		
17	SSA	Sub-Saharan Africa		
18	ROW	Rest of World		

Source: GTAP database version 10(2019), release 6-pre2p

3.2. Simulation Procedures

Two main scenarios: a baseline scenario and a counter-virtual policy scenario, are employed to evaluate the opportunity costs the USA has to pay for meeting the INDC emission targets committed through the Paris climate agreement of 2015. Each simulation is evaluated relative to the benchmark scenario. Needless, the main focus of this study is the changes in simulated values resulting from the re-entry of the USA into the Paris climate agreement and the implementation of her NDC commitments. In other words, the main concern is the impact of CO_2 emission reduction targets by the USA.

Figure 5. Applied CGE Model Schema



Source: Authors drawing

3.2.1. Baseline Scenario

The base scenario structure describes all economies in 2030 under a business-as-usual GHG emission framework. In developing the BAU baseline scenario, we incorporate projected growth rates for GDP, population, capital stock, skilled and unskilled labor, agricultural land, and equivalent GHG emissions. GDP projections are from the SSP2 database (Cuaresma, 2017; Riahi et al., 2017), while the projected population values are from the UN DESA (2019), and physical capital stock supply growth is from Foure, Benassy-Quere, and Fontagne (2012), Skilled and Unskilled labor is from SSP2, while the projected arable land growth is from Bruinsma (2011), while CO_2 emission projections are from Fenhann (2022). Following the GTAP database version 10 base year, all macroeconomic projections are benchmarked to 2014.

3.2.2. Policy Scenarios

Next, we design the counter-virtual policy experiments while assuming that all countries meet their CO_2 emission reduction targets (INDC) committed through the Paris climate agreement of 2015 and the COP26 conference. The study adopts two main policy experiments, where the implementation of each policy experiment involves four scenarios. Two scenarios out of the four in each policy experiment adopt a prescriptive regulatory approach, while the other two apply the market-oriented approach or the flexibility mechanism, which includes emission trading (ET) and joint investments.

Table 2. CO_2 Emission Reduction Targets for Policy Scenarios

Region/ Experiment / Scenario	CO_2 Emission Reduction with no Use of Flexibility Mechanisms Excl / Incl USA		CO_2 Emission Reduction with Trading Excl/Inc USA		CO_2 Emission Reduction no Use of Flexibility Mechanisms by Major GHG Emitters Excl/ Incl USA		CO_2 Emission Reduction by major GHG Emitters with Trading Excl/Inc USA	
	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	Sc7	Sc8
Korea	40% compared with 2018							
Japan	46-50% compared with 2013							
China	65% compared with 2005							
United States of America	50-52% compared with 2005							
United Kingdom	68% compared with 1990							
South Africa	37-43% compared with 201							
Kenya	32% compared with 2030							
Rwanda	16-38% compared with 2030							
Tanzania	20.51-50.57% compared with 2030							
Uganda	22% compared with 2030							
Ethiopia	14-69% compared with 2030							
Former Soviet Union								
Other Industrial Countries								
Oil Exporting Countries								
European Union27	55% compared with 1990							
North Africa								
Sub-Saharan Africa								
Rest of World								

Source: Fenhann Joergen, UNEP Copenhagen Climate Centre (April 1, 2022),

Reference for Applied Experiments:
1. Scenario 1 and 2 forms experiment 1 abbreviated as NeMTRD
2. Scenario 3 and 4 forms experiment 2 abbreviated as WeMTRD
3. Scenario 5 and 6 forms MeMNTRD experiment 3 abbreviated as MeMNTRD
4. Scenario7 and 8 forms MeMTRD experiment 4 abbreviated as MeMTRD

The market-oriented framework provides greater flexibility in the re-allocation of resources in determining how to reduce CO_2 emissions hence, reduced abatement costs. We account for the USA's commitment or non-commitment to the 2015 Paris Climate Agreement in both the prescriptive regulatory and market-oriented approaches. Cumulatively eight distinct scenarios are implemented. Scenarios 1 to 4 focus on global CO_2 emission reduction with and without trading. Scenarios 5 to 8 are formulated to capture the economy-wide impact of CO_2 emission reduction by the major GHG emitters bloc. The carbon emission quotas refer to NDC commitments through the Paris climate agreement frameworks and remains the same for all scenarios.

IV. Simulation Results

The implementation of greenhouse gas (GHGs) reduction targets by states is through national mitigation and adaptation policies and requires a significant adjustment in the country's economic structures. However, proper balancing is necessary to minimize the inefficiency in the reallocation of a country's limited resources.

Table 3. Impact of Carbon Emission Reduction on Real GDP (total % change) Sc4-Sc3

Region \ Experiment / Scenario	WNeMTRD		WeMTRD		MeMNTRD		MeMTRD	
	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	Sc7	Sc8
Korea	-2.68	-2.69	-0.12	-0.22	-0.22	-0.46	-0.22	-0.46
Japan	-1.86	-1.85	-0.05	-0.10	-0.17	-0.34	-0.17	-0.34
China	-0.42	-0.41	-0.44	-0.69	-0.52	-0.97	-0.52	-0.97
United States	0.01	-0.64	-0.13	-0.24	-0.16	-0.36	-0.16	-0.36
United Kingdom	-4.00	-4.01	-0.06	-0.11	-0.13	-0.24	-0.13	-0.24
South Arica	-0.23	-0.18	-0.52	-0.86	0.03	0.04	0.03	0.04
Kenya	2.24	1.84	0.40	0.59	0.00	-0.01	0.00	-0.01
Rwanda	0.14	0.12	0.05	0.07	-0.01	-0.01	-0.01	-0.01
Tanzania	0.30	0.23	0.09	0.13	0.01	0.01	0.01	0.01
Uganda	0.08	0.06	0.02	0.03	0.00	0.00	0.00	0.00
Ethiopia	0.77	0.84	0.41	0.65	0.01	0.01	0.01	0.01
Former Soviet Union	-0.49	-0.45	0.59	0.56	-0.03	-0.10	-0.03	-0.10
Other Industrial Countries	-0.31	0.00	-0.11	-0.19	0.02	0.03	0.02	0.03
Oil Exporting Country	-0.16	-0.18	-0.21	-0.34	-0.03	-0.06	-0.03	-0.06
EU27	-2.19	-2.18	-0.09	-0.14	-0.19	-0.34	-0.19	-0.34
North Africa	0.00	0.00	-0.19	-0.32	0.00	0.00	0.00	0.00
Sub-Sharan Africa	-0.11	-0.01	-0.01	-0.02	-0.01	-0.03	-0.01	-0.03
Rest of the World	0.00	0.02	-0.10	-0.18	0.03	0.05	0.03	0.05

Source: Authors' calculation

Table 3. displays the effects of policy scenarios 1 to 8 on real GDP. This study focuses on Scenarios 3 and 4 that implement a market approach to global CO_2 emission reduction while excluding and including the USA, respectively. Simulation results show that all major GHG emitters are likely to suffer a decline in GDP growth. For instance, Korea is expected to face a decline in real GDP of 0.12% and 0.22%, with Japan China, UK, and EU27 facing a decline of 0.05% and 0.10%; 0.44% and 0.69%; 0.06% and 0.11%; and 0.09% and 0.14%, respectively.

In contrast, all the East African countries and the former Soviet Union region will likely experience an increase in their real GDP, with Kenya and Ethiopia being the biggest beneficiaries, with real GDP likely to rise by 0.24% and 0.38% and 0.24% and 0.39%, respectively. However, the real GDP for Tanzania will decline by 006% and 0.09%. The real GDP for Rwanda and Uganda will drop by 0.03% and 0.05, and 0.02 % and 0.02%, in both scenarios 3 and 4, respectively. On the contrary, the other hand, the real GDP of the Former Soviet Union will increase by 0.49% and 0.58% in both scenarios, respectively.

On the other hand, the real GDP for other industrialized countries (OIC) and the oil-exporting countries (OEX) will decline by 0.06% and 0.11%, and 0.11% and 0.20%, respectively. The real GDP for the North-African and the Sub-Saharan-Africa regions shrinks by 0.09% and 0.18%, and 0.01% and 0.01%, respectively. Likewise, the rest of the world (ROW) will suffer a decline in real GDP of 0.05% and 0.10%, respectively. CO_2 emission reduction with ET leads to stabilization in GDP growth for the majority of the regions relative to CO_2 emission reduction with no emission trading. It's worth acknowledging that global CO_2 emission reduction (scenarios 1 to 4) will lead to a decline in GDP compared to CO_2 emission reduction under selected regions, as indicated by simulation results for scenarios 5 to 8. As simulation results of Sc1 show, the real GDP for the USA is unlikely to decline if the USA does not participate in global CO_2 emission reduction. However, if the USA contributes to global emission reduction (Sc2) with no emission trading, its real GDP will decline by 0.62% compared to 0.14% under global emission reduction with trading (SC4). Therefore, the opportunity cost of the USA's CO_2 emission reductions amount to its real GDP of 0.14%.

Table 4. Welfare Change in US$ billion, from USA CO_2 Emission Reduction (SC4-Sc3)

Region \ Experiment / Scenario	NeMTRD		WeMTRD		MeMNTRD		MeMTRD	
	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	Sc7	Sc8
Korea	-19.6	-18.8	-2.4	-3.0	-19.0	-19.5	-5.4	-8.0
Japan	7.0	9.3	0.4	5.2	-5.8	-3.6	-5.5	-8.6
China	-218.6	-208.3	-201.5	-249.0	-196.1	-205.2	-233.8	-308.8
United States	-3.5	-135.7	1.5	-96.0	-1.2	-135.1	5.6	-116.2
United Kingdom	-49.9	-50.5	-8.9	-13.1	-8.5	-52.2	-11.6	-20.6
South Arica	-2.3	-1.9	-3.7	-4.1	0.6	1.5	0.7	1.2
Kenya	26.3	23.8	5.3	7.7	0.0	0.9	0.1	0.1
Rwanda	0.0	0.1	0.1	0.1	0.0	-0.1	0.0	0.0
Tanzania	7.1	7.0	3.2	4.7	0.1	0.2	0.1	0.1
Uganda	1.2	1.2	1.7	2.5	-0.1	-0.3	-0.1	-0.1
Ethiopia	11.6	12.5	7.0	10.2	0.0	0.2	0.0	0.1
Former Soviet Union	-47.5	-52.5	-12.3	-21.3	-10.8	-50.8	-10.7	-19.8
Other Industrial Countries	-43.5	-44.8	-20.4	-27.9	-2.6	-19.2	0.2	-1.7
Oil Exporting Country	-82.6	-102.9	-72.4	-99.9	-22.2	-80.1	-26.0	-43.9
European Union27	-15.2	-7.7	-9.9	-12.8	-2.0	-22.2	-26.1	-40.5
North Africa	-5.9	-6.4	-9.1	-12.0	-1.3	-6.3	-1.5	-2.4
Sub-Sharan Africa	-2.8	-3.7	3.2	5.2	-3.4	-11.9	-4.2	-7.2
Rest of the World	-34.4	-20.5	-30.3	-28.2	14.6	-19.2	19.0	38.5

Source: Authors' calculation

Table 4 displays the effects of policy simulations (scenarios 1 to 8) on welfare in terms of the equivalent variation (EV), which is the money metric equivalent of the change in the utility resulting from the change in price emanating from a policy change. Except for the East African Community (EAC) member states, Japan, Sub-Sharan African (SSA), and the Rest of the World (ROW), all other countries are projected to face a decline in welfare under the global CO_2 emission reduction framework. Likewise, the major GHG emitters bloc are forecasted to experience a decline in EV. Regions where welfare is forecasted to decline sharply include China, the USA, and the oil-exporting member countries.

The drop in welfare within the oil-exporting countries can be attributable to the sharp fall in crude oil prices from the global CO_2 emission reductions since oil is their main export commodity. USA's welfare is likely to decrease by US$124.8 billion and US$74.2 billion under emission reduction with no use of flexibility mechanism scenario (Sc2) and with emission trading scenario (Sc4), respectively. However, if all other countries implement their NDC emission reduction targets with no use of flexibility mechanisms while excluding the USA, the USA is projected to suffer a welfare loss of US$ 0.2 billion. Therefore, the opportunity cost the USA is likely to pay for its CO_2 emission reductions amount to US$124.6 billion and US$74 billion, under no emission trading and an emission trading scenario, respectively.

Table 5. Impact of global emission trading excluding the USA (Sc3) on Domestic Production by Sector in 2030 (total% change)

Sector\ Region	KOR	JPN	CHN	USA	UK	SAF	KEN	RWA	TZA	UGA	ETH	FSU	OIC	OEX	EU27	NAF	SSA	ROW
Agr	-0.4	-0.1	0.1	-0.2	0.0	0.1	-0.2	0.2	0.1	0.0	1.0	0.3	-0.1	0.1	-0.3	0.3	0.0	-0.2
F_F	-0.5	-0.1	-0.1	-0.2	-0.2	-0.2	0.2	0.1	-0.1	0.2	2.2	-0.1	-0.2	-0.2	-0.3	0.0	0.0	-0.1
Coal	-31.3	-40.8	-27.8	-15.2	-10.5	-11.2	-24.5	-17.4	-21.3	-18.8	-0.1	-7.3	2.4	-1.4	-18.0	-33.3	-7.1	-11.1
Oil	-1.6	-1.7	-2.1	-2.8	-2.5	-2.0	-4.9	-1.2	-0.4	-2.8	-2.7	-1.3	-2.5	-1.0	-2.3	-1.9	-2.1	-2.5
Gas	0.2	-0.3	-14.8	-24.4	-19.4	-4.1	-6.3	-3.1	0.0	-4.2	-0.1	-10.7	-9.5	-2.0	-7.8	-4.8	-4.7	-13.4
Oil_pcts	0.4	1.0	-3.3	-2.2	0.1	-5.5	-1.8	-11.3	-11.8	-14.6	-31.1	-0.7	-2.5	-4.2	0.1	-3.9	0.5	-1.0
PrcFood	-0.3	-0.1	-0.1	-0.1	-0.1	0.7	-0.7	0.5	-0.6	-0.6	1.3	0.4	0.0	0.5	-0.3	0.2	-0.1	-0.3
En_Int_Ind	1.4	0.6	-1.3	0.6	1.6	-1.5	-10.4	-0.2	-5.9	-4.2	-8.0	-0.3	2.0	3.2	1.0	0.4	1.0	-1.1
TMV	-1.0	-0.9	-0.1	0.0	0.1	1.8	-9.2	-1.4	-5.0	-5.5	-7.3	0.5	0.7	1.7	-0.3	0.5	-0.8	-0.2
Oth_Ind	-0.8	-0.8	0.2	0.0	0.4	0.8	-10.4	-3.1	-7.9	-6.3	-10.0	1.1	0.9	2.2	-0.2	1.2	-0.7	-1.2
Electricity	-5.1	-2.8	-10.4	-5.3	-2.3	-23.4	0.4	-1.6	0.3	-1.4	1.0	-4.9	-2.3	-4.6	-1.9	-3.9	3.2	-3.7
Construct	-0.1	-0.3	-0.5	-0.2	-0.1	-0.6	1.2	0.3	1.6	1.4	3.1	0.1	-0.1	-0.6	-0.1	-0.1	0.2	1.9
TransportS	-0.1	0.2	-0.5	-0.9	0.4	-3.1	-1.0	-1.2	-6.3	-3.2	-7.7	-0.4	-0.2	-3.0	0.3	-2.4	-0.8	-0.7
OthSvcs	-0.2	-0.1	-0.2	0.1	-0.1	-0.1	0.9	0.0	0.9	0.4	-0.7	0.1	-0.1	-0.3	-0.1	-0.1	0.1	0.0

Source: Authors calculations

Tables 5 and 6 present the effects of policy scenarios 3 and 4 on domestic production by sector. In the case of scenario 3, domestic production by the top GHG emitters declines in all of the energy sectors except for sector gas (+0.2%) of Korea and (+0.4%) +0.1% and +0.1% for oil-products sectors of Korea, Japan, and the EU27, respectively. Regarding domestic production of energy-intensive industries except for China (-1.3%), all top GHG emitters experience an increase in domestic output, with the UK having 1.6%, followed by Korea at 1.4%, the EU27 at 1.0%, while Japan and the USA see a 0.6% increase.

On the contrary, the low CO_2 emitting countries face a drop in domestic output in the same sector while the oil-exporting and other industrialized countries have a 3.2% and 2.0% output, respectively. The NAF and the SSA region also see a positive output of 0.4% and 1.0%, respectively. However, the rest of the world has a negative domestic output of 1.1%. The domestic production of energy sectors such as coal, oil, gas, and electricity of all top GHG emitters is critically and negatively affected by their CO_2 emission reductions. For example, the decline in the domestic production of coal drops by -18.0% for the EU27 to -40.8% for Japan. On the other hand, the domestic output of the electricity sector declined from -1.9% for the EU27 to -10.4% for China. The domestic production in most sectors of the USA decreased, except for the energy-intensive (+0.6%) and other services (0.1%), while domestic output in transport motor vehicles and other industries had no significant change. For instance, the USA's domestic production in agriculture declined by 0.2%, forestry and fishery by 0.2%, processed food by 0.1%, construction by 0.2%, and transport services by 0.9%.

Table 6. Impact of global emission trading excluding the USA (Sc4) on Domestic Production by Sector in 2030 (total % change)

Sector\ Region	KOR	JPN	CHN	USA	UK	SAF	KEN	RWA	TZA	UGA	ETH	FSU	OIC	OEX	EU27	NAF	SSA	ROW
Agr	-0.7	-0.2	0.0	0.0	0.0	0.0	-0.3	0.3	0.2	0.0	1.5	0.4	-0.2	0.1	-0.5	0.3	0.0	-0.4
F_F	-0.8	-0.2	-0.2	0.1	-0.2	-0.4	0.3	0.2	-0.1	0.4	3.4	-0.2	-0.2	-0.3	-0.4	-0.1	0.0	-0.2
Coal	-39.6	-51.5	-37.1	-21.0	-15.4	-16.0	-34.8	-24.1	-29.9	-26.5	-0.1	-11.1	2.0	-2.4	-24.9	-43.3	-10.7	-15.4
Oil	-2.7	-2.7	-3.5	-4.1	-4.0	-3.4	-8.1	-2.0	-0.5	-4.6	-4.5	-2.2	-4.0	-1.6	-3.7	-3.1	-3.5	-4.2
Gas	0.3	-0.4	-22.4	-34.4	-30.5	-6.4	-10.5	-5.2	0.0	-7.1	-0.1	-15.0	-13.7	-2.6	-11.6	-6.8	-7.1	-19.2
Oil_pcts	0.6	1.5	-5.2	-3.6	0.2	-8.6	-2.6	-16.9	-17.6	-21.6	-42.7	-1.2	-4.0	-6.6	0.1	-6.2	0.6	-1.7
PrcFood	-0.6	-0.2	-0.2	-0.1	-0.1	0.9	-1.1	0.8	-0.9	-1.0	2.0	0.7	-0.1	0.7	-0.5	0.3	-0.1	-0.5
En_Int_Ind	2.1	0.9	-2.1	1.9	2.6	-2.6	-15.8	-0.5	-9.5	-6.6	-12.7	-0.7	3.2	4.9	1.5	0.5	1.5	-1.9
TMV	-1.8	-1.7	-0.3	0.9	0.1	2.2	-14.0	-2.2	-8.0	-8.7	-11.6	0.6	0.8	2.6	-0.5	0.7	-1.2	-0.8
Oth_Ind	-1.1	-1.0	0.0	1.5	0.9	1.0	-15.7	-4.8	-12.1	-9.6	-15.2	1.8	1.6	3.5	-0.2	1.8	-1.0	-2.0
Electricity	-7.8	-4.4	-14.7	-8.0	-3.5	-31.9	0.7	-2.5	0.5	-2.1	1.1	-7.6	-3.4	-6.4	-2.9	-5.7	4.7	-5.7
Construct	-0.1	-0.5	-0.7	-0.5	-0.1	-0.8	1.8	0.4	2.6	2.3	4.8	0.1	-0.2	-0.9	-0.1	-0.2	0.3	3.2
TransportS	-0.4	0.3	-0.8	-1.2	0.5	-4.7	-1.6	-1.9	-9.7	-5.0	-12.1	-0.7	-0.3	-4.7	0.3	-3.8	-1.3	-1.1
OthSvcs	-0.3	-0.1	-0.3	-0.1	-0.1	-0.1	1.4	0.0	1.4	0.7	-1.0	0.2	-0.1	-0.5	-0.2	-0.1	0.1	0.0

Source: Authors' calculations

In case the USA implements its roadmap to reduce GHG emissions as intended (scenario 4), with worldwide emission trading, USA's domestic production in all sectors except agriculture, forestry and fishery, energy-intensive industries, transport motor vehicles including sector other industries, will drop. The USA's domestic production of coal, oil, gas, oil products, and electricity decreases by 21.0%, 4.1%, 34.4%, 3.6%, and 8.0%, respectively. With emission trading, domestic production of USA's energy-intensive industries rises, for instance, by 1.9%, in transport motor vehicles by 0.9%, and by 1.5% in sector other industries. However, if the USA does not implement its CO_2 emission target reduction, domestic production of energy-intensive industries increases by 0.6%. However, domestic output in transport motor vehicles and sector, other industries do not change significantly (is 0 %). Therefore, the opportunity costs the USA is likely to pay for CO_2 emission reductions are immense in energy sectors and transport services, which amount to a decrease in domestic production of 6.2 % in coal, 1.9 % in oil, 10.0% in gas, and 1.4% in oil products, as well as 2.6% in electricity, and 0.3% in transport services.

V. Concluding Remarks

This study attempts to quantitatively evaluate the potential worldwide economic impact of the reduction of CO_2 emissions by the USA and the opportunity cost the USA is likely to pay. The study implements two counterfactual policy experiments (4 scenarios for each experiment) using the GTAP-E CGE model. To account for the exit and re-entry of the USA into the Paris climate agreement of 2015, each of the two experiments focuses on emission reduction with no use of flexibility mechanisms (2 simulations scenarios) and CO_2 reduction with ET (2 simulation scenarios), while excluding and excluding the USA, respectively. The worldwide CO_2 emission reduction involves all regions, while the top GHG emitters trading bloc includes China, the USA, the EU27, the UK, Japan, and Korea. All economies have been projected to 2030 relative to 2014, using macroeconomic projections and the projected CO_2 equivalent GHG emissions under a BAU framework.

Simulation results indicate that all members of the major GHG emitting trading bloc are expected to suffer in terms of GDP growth under scenarios 3 to 8. A review of simulation results indicates that the loss in GDP is likely due to the decline in domestic output in coal, oil, gas, oil, oil products, electricity, and the transport services sector. Nevertheless, in some regions, domestic production in some sectors such as the electricity sector is shown to increase. However, the increase in production in these sectors is not enough to neutralize the loss from the other remaining sectors. Furthermore, the composition of the energy mix may explain why domestic production in the electricity sector in some countries is not impacted negatively by CO_2 emission reduction. For example, in 2020, Kenya's energy mix is 93% renewable energy and 7% thermal. On the contrary, regarding the low GHG emitting regions, which include Kenya, Rwanda, Tanzania, and Uganda, their economies are shown to rise under world emission trading scenario 4. On the other hand, under the major GHG emitters trading bloc experiment, China and Korea were the biggest beneficiaries, where real GDP losses reduced by 0.04% and 0.03%, respectively. Overall, the decline in real GDP is due to the decrease in domestic production, especially in the five energy sectors; coal, oil, gas, oil products, and electricity, and the transport services and construction sectors.

With respect to welfare, all major GHG emitters are expected to lose under all four scenarios as reflected in their economic growth. Among the major GHG emitters Korea is expected to be least affected with welfare declining by between $2.38 billion (Sc8) to $4.98billion (Sc6) indicating that emission trading cushions Korea's welfare by $2.6 billion. The impact on Japan's welfare is relatively small compared to other major GHG emitters. However, in terms of welfare loss, China is the most affected followed by the USA. Simulation findings indicate that the decline in China's welfare is expected to lie between $101.09 billion and $144.22 billion while USA's welfare is likely to decline by between $4.97 billion and $80.43 billion. The EU27 welfare is expected to decrease by $ 14.02 billion to $24.73 billion, the Oil exporting countries are also expected to suffer significantly by$ 13.11 billion to $ 25.21 billion. Analyzing results from the welfare decomposition facility indicates that welfare loss emanates from allocative inefficiencies, CO_2 emission trade imbalance and loss in investments.

In condition, the USA implements its roadmap to reduce greenhouse gas emissions as planned under the global CO_2 emission trading experiment scenarios 1 to 4, its domestic production declines more under the no trading scenario, with Coal declining by 39.49%, Oil by 6.51%, Gas by 60.06%, Oil products by 16.03%, and Electricity by 20.19%. Under the CO_2 emissions reduction with trading USA's domestic production of Coal decreased by 20.83%, Oil by 2.42%, Gas by 30.72%, Oil products by 4.76%, and Electricity by 8.96%. Empirical findings show that USA's domestic production under the no CO_2 emissions reduction by major GHG emitters declines by approximately 50% compared to global CO_2 emission reduction with no use of flexibility mechanism. Strikingly, for the USA, the domestic production of the energy-intensive industries increases under the global CO_2 emission reduction with no use of flexibility mechanism by 1.79% but increases under global CO_2 emission reduction with emission trading by 0.91% CO_2 emission reduction with no use of flexibility mechanism by major GHG emitters, and 0.76% with trade under major GHG emitters, respectively.

There are significant opportunity costs of CO_2 emission reductions by the USA, especially in the transport and energy sectors, since these amount to a decrease in domestic production of 38.61% in coal, 58.54% in gas, 5.91% in Oil, and 15.56% in oil products, 20.13% in electricity, and 9.00% in transport.

The findings of this study validate prior studies on the capacity of the market-oriented approach to reduce the marginal abatement costs associated with CO_2 emissions reduction since it provides greater flexibility in the re-allocation of resources. Further, simulation results and the available literature support the need to strengthen the global CO_2 emission flexibility mechanisms, CO_2 taxation, and policies that can ensure a smooth transfer of technologies to enhance energy efficiency (Ko, Jong-Hwan, 2014; IRENA, 2021). Notwithstanding, governments should engineer regulatory instruments that fix minimum efficiency standards in buildings, appliances, vehicles, and industry; fiscal or financial incentives to increase the viability of installing energy-efficient equipment; and information programs to help energy users make informed decisions (IRENA, 2021). The outcome of this study further suggests the need to address the free-rider debacle since the inclusion of all states leads to relatively lower marginal abatement costs.

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