Correlation Between Representative Concentration Pathways and Paris Agreement

Stavros Lazarou*‡, Lambros Ekonomou*, Athanasios Dagoumas**

* Department of Electrical and Electronic Engineering Educators, School of Pedagogical & Technological Education (ASPETE), Heraklion Attikis, 141 21 Athens, GR

** School of Economics, Business & International Studies, University of Piraeus, 80 Karaoli & Dimitriou Str., 18534 Piraeus, Greece

(slazarou@ta.aspete.gr, leekonomou@aspete.gr, dagoumas@unipi.gr)

‡ Corresponding Author; Stavros Lazarou, Heraklion Attikis, 141 21 Athens, GR, Tel: +30 210 2896-927, slazarou@ta.aspete.gr

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Abstract- Paris Agreement stands as the flagship of ongoing international climate change agreements. The agreement's aim is generic and therefore meeting its targets of maintaining 2 degrees of Celsius temperature increase from the pre-industrial levels is not a strictly deterministic problem but rather a complex probabilistic issue. Having mentioned the above, this paper aims at correlating Paris Agreement with Representative Concentration Pathways (RCPs) over the end of the century, using as starting point the RCP2.6 scenario and consequently proposing and examining pathways that involve substantial decrease of emissions compared to RCP2.6, namely RCP 2.0 and RCP1.0. The results, through the elaboration of an integrated assessment tool (GCAM), provide useful insights on extended pathways for meeting Paris Agreement targets. Our findings include the requirement of major negative emissions. Industrialized and developing countries have substantial contribution, mostly based on their population rather than their economic situation.

Keywords Representative Concentration Pathways; Paris Agreement; Climate Change; Carbon emissions.

1. Introduction

The Representative Concentration Pathways (RCPs) [1], [2] are considered as predefined climate scenarios used for research and decision making. On the other hand, Paris Agreement is an international treaty dealing with climate change mitigation. Paris Agreement [3] adopted by consensus at the 21st Conference of the Parties (COP) of the United Nations Framework Convention on Climate Change (UNFCCC). The Similarly, to the Kyoto Protocol [4], the ratification of the Paris Agreement required 55 UNFCCC Parties. Those limitations have been met within few months, in contradiction with the Kyoto Protocol where the ratification process lasted almost 8 years, from 1997 to 2005. This rapid process provides a clear signal that there is a global consensus on tackling climate change potential threats.

Correlation of Paris Agreement [3] and Representative Concentration Pathways (RCP) [5] [6] has been a matter of extensive scientific debate. The difficulty of this research question is based on lack of scientific consensus, which RCP could adequately cover Paris Agreement requirements as far as carbon emissions are concerned. According to several scientists, "t(T)he RCP 4.5 scenario is particularly important, because … there is a reasonably good probability (~75 %) the Paris target will be achieved…" [7]. This probability, 75% is considered as inadequate; hence, it has been decided that RCP4.5 is not to be simulated in this article. On the other hand, other scientists [8] support the opinion that even more optimistic RCPs such as 2.6 cannot provide certainty than Paris Agreement commitments would be fulfilled. Under these circumstances, it is necessary to understand how emission pathways stricter than RCP2.6 could be more effective in this direction.

As a matter of fact, meeting Paris Agreement requirements remain a complex exercise per se. A critical issue in the implementation of the Paris Agreement, as well as of the climate negotiations, is the contribution of different UNFCCC members. Initial studies that analyzed a plethora of Integrated Assessment Model results indicate significant risk for a 2 degrees Celsius temperature decrease not to be achieved [9]. Later on, other studies indicate that the emissions reductions of the Intended Nationally Determined Contributions (INDCs) submitted after Paris Agreement would be inadequate to achieve its goals [10] and additional incentives towards meeting its targets are required [11]. Pan X. et. al., [12] explore fair and ambitious mitigation contributions under the Paris Agreement goals. Even INDCs for G7 countries, which are expected to act as a paradigm for the rest of the world, are to a certain degree problematic [13]. In higher resolution on country level, Ari and Sar [14] focus on the differences among developed and developing countries. The paper ranks countries based on differentiation proposals for classification of developed and developing countries particularly on mitigation of greenhouse gas (GHG) emissions by using data from the world's top 50 emitters. However, the paper concludes that new definition and criteria should be set to define all countries' responsibilities, as the classifications based on the Annex system of the UNFCCC do not give a clear reference point to define developed and developing countries.

Some researchers focus in the feasibility of the Paris Agreement, providing contradicting approaches: optimistic, neutral or pessimistic. Kern F. and K.S. Rogge [15] examine the dynamics of governed energy transitions. Gao Y. et. al. [16] examine the evolution of global temperature target up to the 2 °C within the Paris Agreement.

Ghezloun A. et. al. [17], examine the evolution of the Paris Agreement, focusing on the COP 22 new commitments. In Marrakesh, governments have made progress in key areas of climate action, especially in climate finance. Parties welcomed the progress made by donors of funds to achieve the goal of jointly mobilizing $ 100 billion annually by 2020, while several Member States of the European Union also promised more than $ 81 million to the Adaptation Fund. Overall, the Green Climate Fund is on the way to approve $ 2.5 billion to allocate to projects.

On the other hand, Nieto J. et. al. [18] provide an economic-environmental evaluation of the Paris Agreement and more pessimistic expectations. The paper evaluates the Paris Agreement feasibility, regarding the Intended Nationally Determined Contributions (INDCs) and its economic and environmental constraints. The INDCs are analyses based on criteria that consider socio-economic impact of the transition, focus on energy management, substitution of non-renewable sources, the role of technology, equality of the transition and the compliance with emission reductions. The paper identifies the implementation of climate policy agreements, such as the Paris Agreement, require comprehensive quantitative analysis, as was undertaken in the past for the Kyoto Protocol [4].

Dovie D.B.K. and S. Lwasa [19] focus on the negotiations on the COPs, which is an important factor of local climate policy coordination. They aim to correlating negotiation hotspot issues, Paris climate agreement and the international climate policy regime. They claim that the success of the ‘ambitious targets’ for mitigation will depend on similar ambitious goals for adaptation, land use and sustainable development.

Finally, there are several studies that focus on specific technologies or energy carriers, namely how they are affected and how they could contribute to the implementation of the Paris Agreement. Foley A. et. al. [20] provide a technological analysis. Peters J.C. [21] has focused on natural gas on the United States. Arantegui R.A. and A. Jäger-Waldau [22] argue on the Paris Agreement as important pillar in European climate and energy policy. Koo B. [23] examine the hydropower projects in the post-Paris regime. Mattiasson B. [24] examines biotechnology potential to meet Paris Agreement. Coope M. [25] examines the role of distributed renewable generation. Lee D.H. [26] provide an evaluation of the development of biobutanol. Van de Graaf T. [27] focuses on the reduced role of crude oil, following the Paris Agreement. It moreover examines the role of the Organization of Petroleum Exporting Countries (OPEC) over the transition to a post-carbon world.

Several researchers focus on specific issues, within the Paris Agreement or Kyoto Protocol implementation process. Duque, E. et. al. [28] gives emphasis to Colombia. Sreekanth, K.J. et. al. [29] analyse the contribution of certified emission reductions to rural areas. Duque, E. et. al. [30] explain the implementation of ACM0002 methodology the Clean Development Mechanism. E. Moreci, et al [31] give emphasis to the Italian system. M. Longo et. al. [32] analyse the system in general. F. Viola et al see the environmental benefits of the system.

Meeting deep emission reduction targets might be implemented by emission pathways that require lower carbon emissions. However, such an approach demonstrates negative carbon emissions for long time. It is a matter of concern on which degree this can be sustained in terms of carbon absorption from natural and artificial sinks. Several studies have been conducted to describe more analytically the phenomenon [34] and [35], both of which demonstrate the complexity of the situation in terms of societal challenges. Despite its importance, this subject remains outside the interests of this research, even if substantial negative emissions are proposed from our simulation patterns.

From the above analysis, Paris Agreement has been thoroughly examined. However, the relationship of the Paris Agreement with the Representative Concentration Pathways has not been examined. This is the first aim of this paper. Moreover, the above analysis identifies that the assessment of climate policy agreements requires robust quantitative approaches, in order to provide useful insights for decision makers and the research community. This stands a second supplementary aim of the paper, namely to provide simulated correlations among the Paris Agreement and the Representative Concentration Pathways.

There is no direct correlation among RCPs and the Paris Agreement targets. The most comparable RCP is the RCP2.6. This study, in order to explore pathways of meeting Paris Agreement requirements, examines the RCP2.6 scenario as well as more ambitious scenarios, by proposing and examining RCP 2.0 and RCP1.0 scenarios.

2. Problem Formulation and Input Data

Simulations for this study were performed on Global Change Assessment Model (GCAM). GCAM has already proven its capability to provide results on research related to Paris Agreement [36] and [37]. Using GCAM, policy makers are facilitated to take informed decisions on future carbon emissions. GCAM [38] [39] is an open source, market equilibrium model that simulates climate change related emissions. Each of the cycles explains the situation in a given time slot. The information of the previous cycle provides the data for the following step.

GCAM observes limitations that are geographically expressed, as well as, policy and technology oriented. The input data include a wide selection of information on sectors contributing to carbon emissions including: industry, transport, energy, and agricultural activities. These input data are aggregated to geographical regions based on socioeconomic criteria such as active population, and gross domestic product. The geographical regions are valuable for simulations on global level but the resolution expressed in continents or wide geographical regions limits the capabilities of country level specific results.

The model can project information in 5 years' intervals up to 2100. This projection is based on the input data from the years 1990, 2005 and 2010. Input data require to be consistent and accurate. Having this said, they have to include the above-mentioned information, organized in two main datasets, the energy system considerations that contain the bulk amount of emissions and the socioeconomic data, which provide the foundations in understanding the contribution of each sector. Simulation assumptions include population, labor productivity, technological characteristics and policies. Model output include carbon emissions, prices, energy supplies and demands, agricultural production, land use, concentrations and temperature [40].

Socioeconomics dataset [41] includes macro-economic, agriculture and land-use considerations. The above affect considerably the results of the model, on a variety of matters and as such are considered as necessary. Macro-economic information displays active population, job participation, country level gross domestic product and its expected growth. The capability of the population to produce provides wealth to the country and affects carbon emissions if it is served energetically by fossil fuels. Agricultural sector is considered to the degree it affects emissions as a factor of absorbing carbon and producing it. Forestry sector provides the raw material for biomass energy production and arable land competes for land use with space demanding renewables, for example solar.

Energy system dataset [42] is methodologically organized in depleted and non-depleted resources. Non-depleted resources include renewables only. Depleted resources are coal, oil, gas and uranium. All the resources require facilities to be exploited, refined, transformed and distributed. These facilities have an installation, operation and end-of-life cost. They participate to a global competitive market based on the projection of data up to the end of the century. The system observes the constraints imposed by the user and provides potential solutions.

Assumptions and input data are used by GCAM solver to create a market equilibrium. For each simulation step all markets are solved using Broyden method for non-linear equation systems [43]. If we have n non-linear equations:

$$\mathbf{f_j(x_1, x_2, x_3, \dots, x_n) = 0, j = 1, 2, .., n}$$

or more concisely

$$\mathbf{f(x) = 0}$$

where f is the column vector of functions and x is the column vector of variables [44]. Then it is solved as:

$$\mathbf{B(x)\delta x = -f(x)}$$

δx is the correction step applied to each simulation iteration up to the point that f(x) is adequately small. B(x) is the secant approximation to the Jacobian matrix of first derivatives of f(x). The user may choose several solver parameters such as its tolerance and the maximum number of iterations.

This study simulates emission pathways that could be RCP 2.0 and 1.0. It has to be mentioned, that these emission pathways are not widely accepted as such, but rather they express a potential approach towards further decreasing carbon emissions. This would also increase the probability for Paris Agreement to be successfully implemented.

2. Results and Discussion

Our simulation results are organized in three Representative Concentration Pathways. These are 2.6, which is consistent to [5] and 2.0, 1.0, which are produced through GCAM simulations. Those scenarios as mentioned in the introduction section, are considered in our analysis as representative scenarios that provide insights for the Paris Agreement. The source code for RCP 2.0 and 1.0 is available at Harvard Dataverse [45]. RCP2.6 is simulated according to the default GCAM settings. As expected, carbon emissions require to be reduced according to Fig. 1. For RCP 2.6 emissions are remain almost steady up to 2035, after of which they decrease on an approximate rate of 1000MTC per 5 years' interval. For RCP 2.0 this reduction of 1000MTC appears 5 earlier. Carbon emissions reduction for RCP 1.0 is importantly rapid to the level of achieving nearly zero global emissions after 2045 and from 2050 anthropogenic emissions become negative. Negative emissions are also observed for RCP 2.6 and 2.0 after 2070 and 2065 respectively. For all three cases, there is a lower sealing on emissions at nearly minus 9000 MTC, which are observed at 2090 for RCP 1.0 and 2100 for RCP 2.0. RCP2.6 demonstrates its minimum also at 2100 for almost minus 8000 MTC.

The following sections provide analytical results for each of the RCP scenarios. The aggregated emissions presented in Fig.1, are analyzed in more detail for each of the thirty-two (32) GCAM geographical regions and for each RCP under investigation. They are grouped in eight (8) regions figures for each RCP.

From our analysis, most of the European countries start demonstrating negative emissions only after 2090 as it appears at Fig. 3. China starts its negative emissions at 2065 and they maximize at 2080.

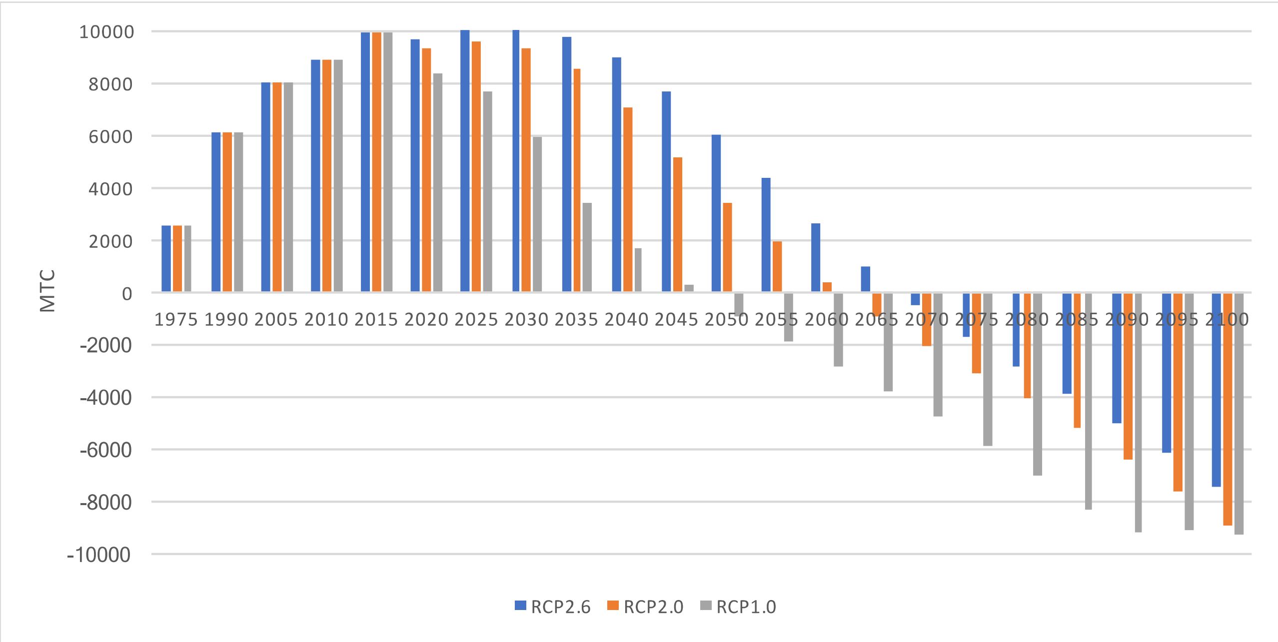

Fig. 1. Global emissions in million carbon tons per Representative Concentration Pathway

The analysis of the results is organized according to GCAM geographical regions and RCPs.

2.1. RCP2.6 scenario

Figure 2 is for RCP2.6 and depicts the situation for USA, Africa, Australia, New Zealand, Brazil and Canada. At 2060, part of Africa and Brazil demonstrates negative carbon emissions. This also happens for USA, Australia and New Zealand at 2065. Only Canada starts having negative emissions after 2070.

Another populous country, India, demonstrates negative emissions after 2085, as shown in Fig. 4. For Japan, the negative emissions turning point is at 2070. Mexico, Middle East and Russia become negative as far as emissions are concerned five years ahead.

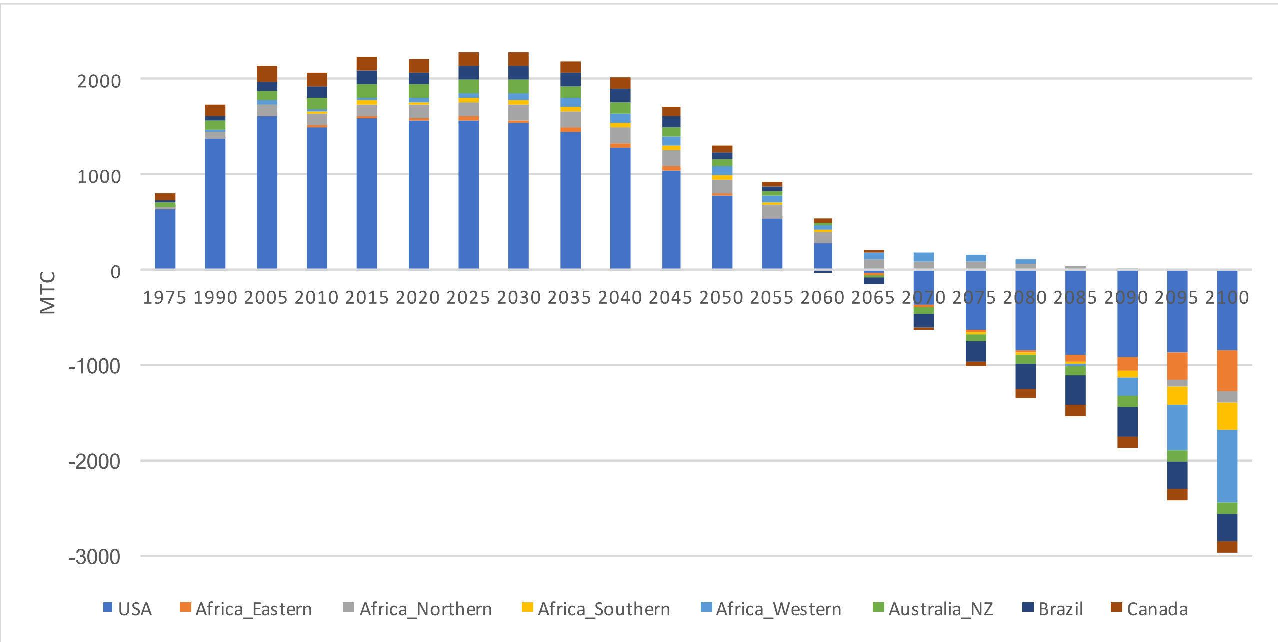

Fig. 2. Emissions in million carbon tons for specific GCAM regions under RCP2.6

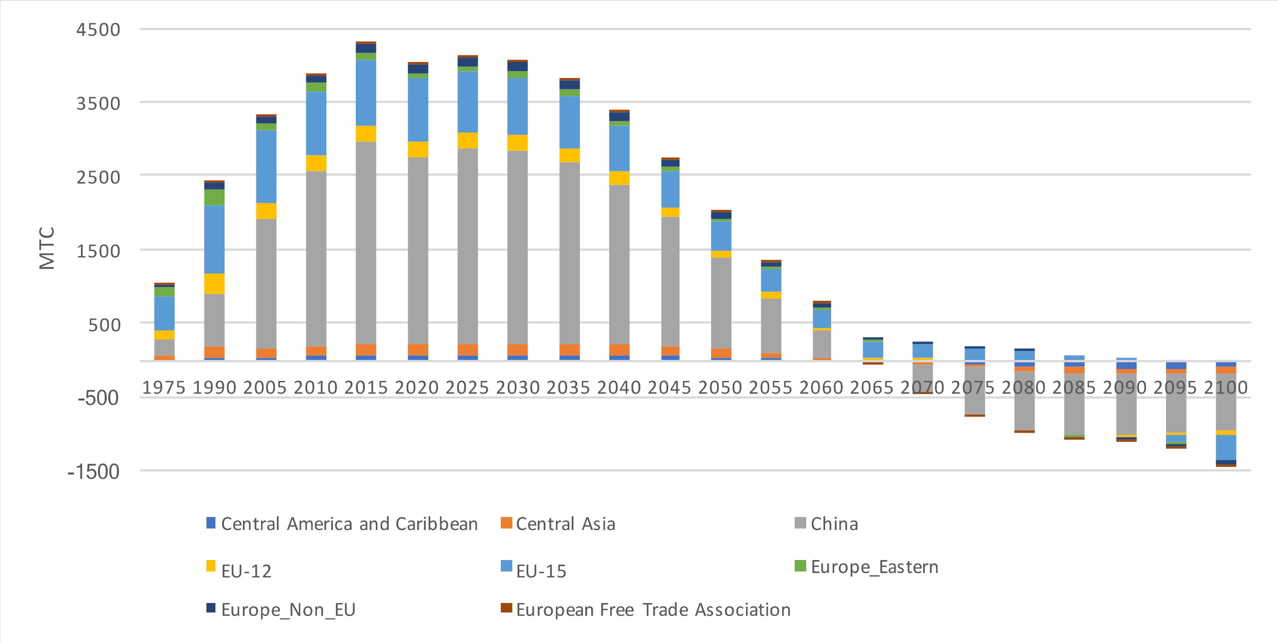

Fig. 3. Emissions in million carbon tons for specific GCAM regions under RCP2.6

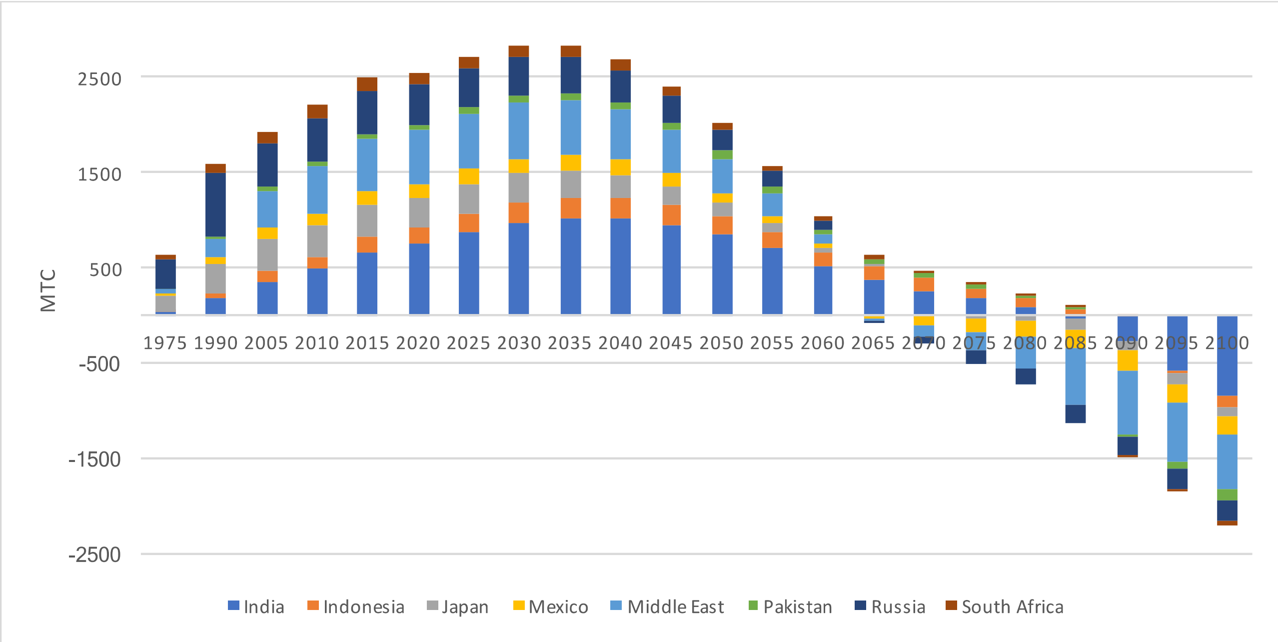

Fig. 4. Emissions in million carbon tons for specific GCAM regions under RCP2.6

The rest of the countries demonstrate minor carbon emissions compared to global emissions, as shown in Fig. 5. Hence, the reduction and eventually negative emissions are relatively lower. With these countries, that global emission setting is completed for RCP2.6.

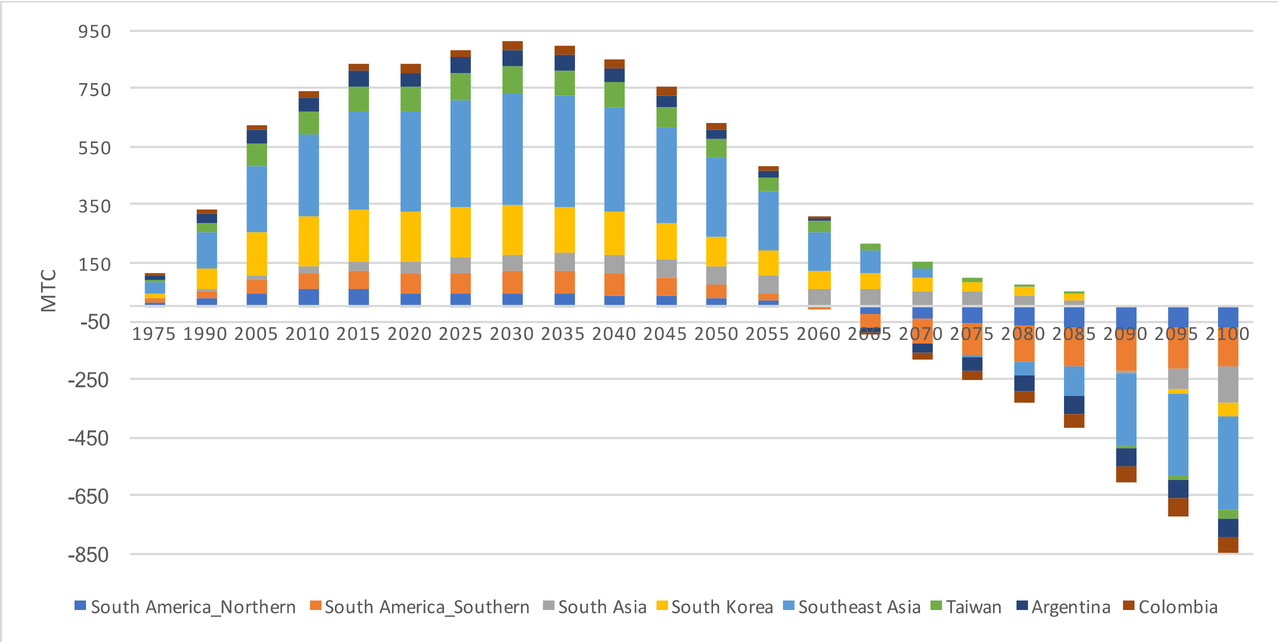

Fig. 5. Emissions in million carbon tons for specific GCAM regions under RCP2.6

2.2. RCP2.0 scenario

RCP2.0 is an estimation of the authors. In this case, we predicted global carbon emissions based on the assumption that this pathway could represent the situation for a potential representative concentration pathway similar to 2.0. In comparison to RCP2.6, carbon emissions are substantially decreasing. As it appears at Fig. 6 and Fig. 2, negative emissions for USA start five years earlier at 2060 and for Canada ten years earlier than before at 2060. Additionally, the volume of the expected emissions is substantially increasing for each geographic region. It reaches a minimum for the US at 2090 and then increases to the end of the century. Similar behaviour applies to Canada and Brazil.

As it appears to Fig. 7 compared to Fig. 3, carbon emissions expected reduction is increasing here as well. Similarly to the previous cases, expected carbon emissions from the European countries and China is expected to

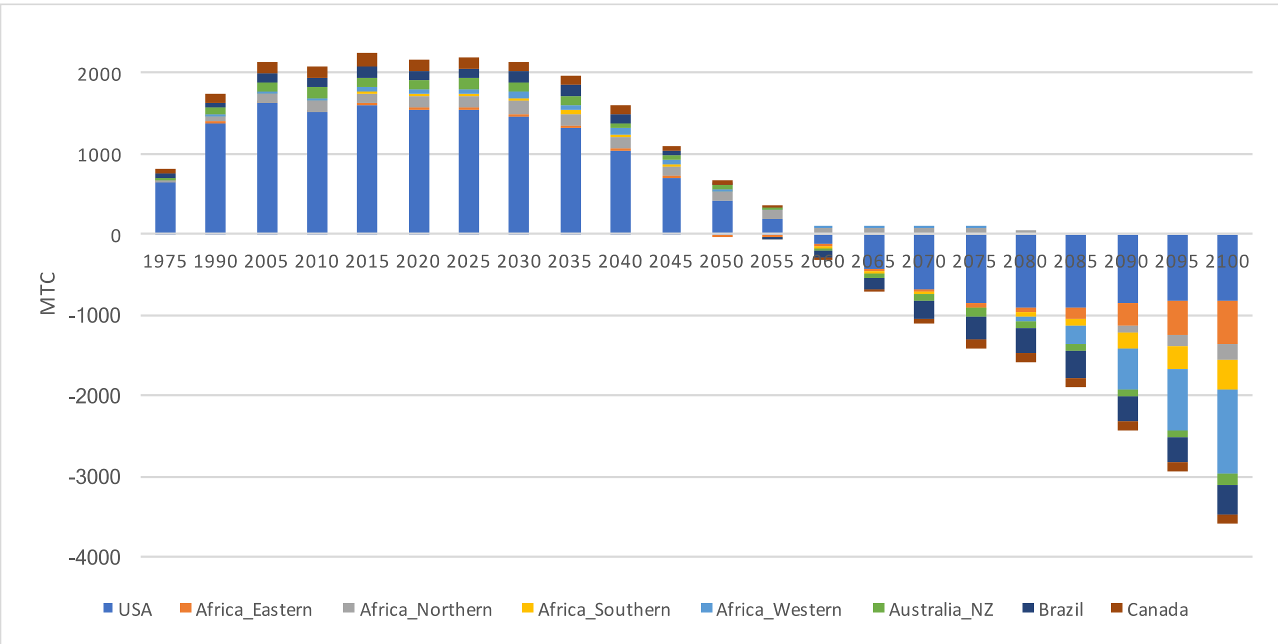

Fig. 6. Emissions in million carbon tons for specific GCAM regions under RCP2.0

become negative five years ahead. Emissions volume for the European countries decreases steadily, demonstrating its minimum at the end of the century. For China, there is a local minimum at 2080 and then emissions increase up to 2100.

production has to decrease its emissions up to 2085 and then they increase to the end of the century. However, Japan has negative emissions already at 2060.

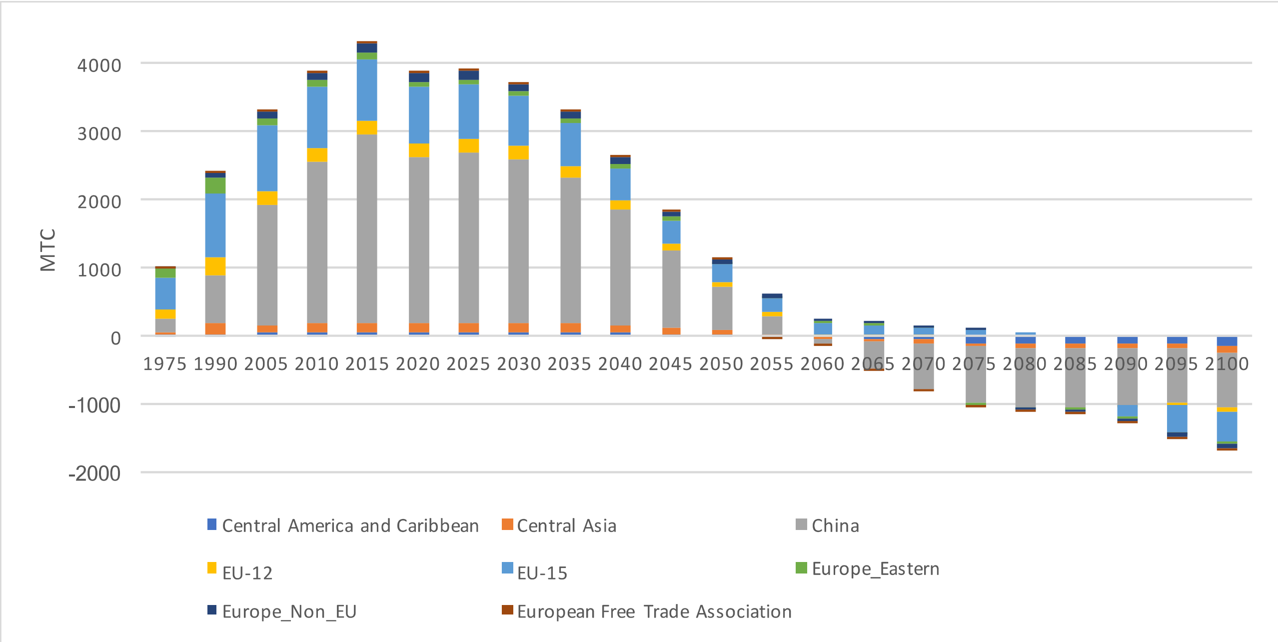

Fig. 7. Emissions in million carbon tons for specific GCAM regions under RCP2.0

For India, there steady decrease across the century, as shown in Fig. 8. Country's emissions are becoming negative after 2080, five years earlier than before. Japan, being an industrialized country without major domestic fossil fuel

The last group of geographic regions, depicted at Fig. 9 demonstrates minor, compared to global emissions contribution. However, it observes similar patterns of emissions decrease.

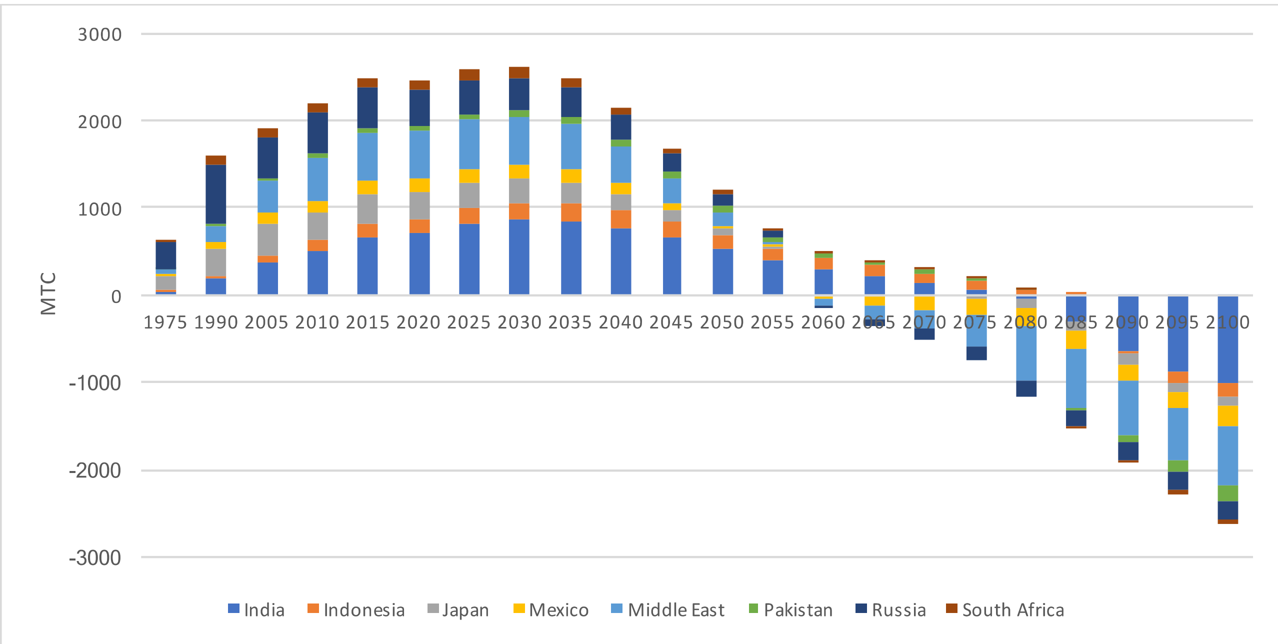

Fig. 8. Emissions in million carbon tons for specific GCAM regions under RCP2.0

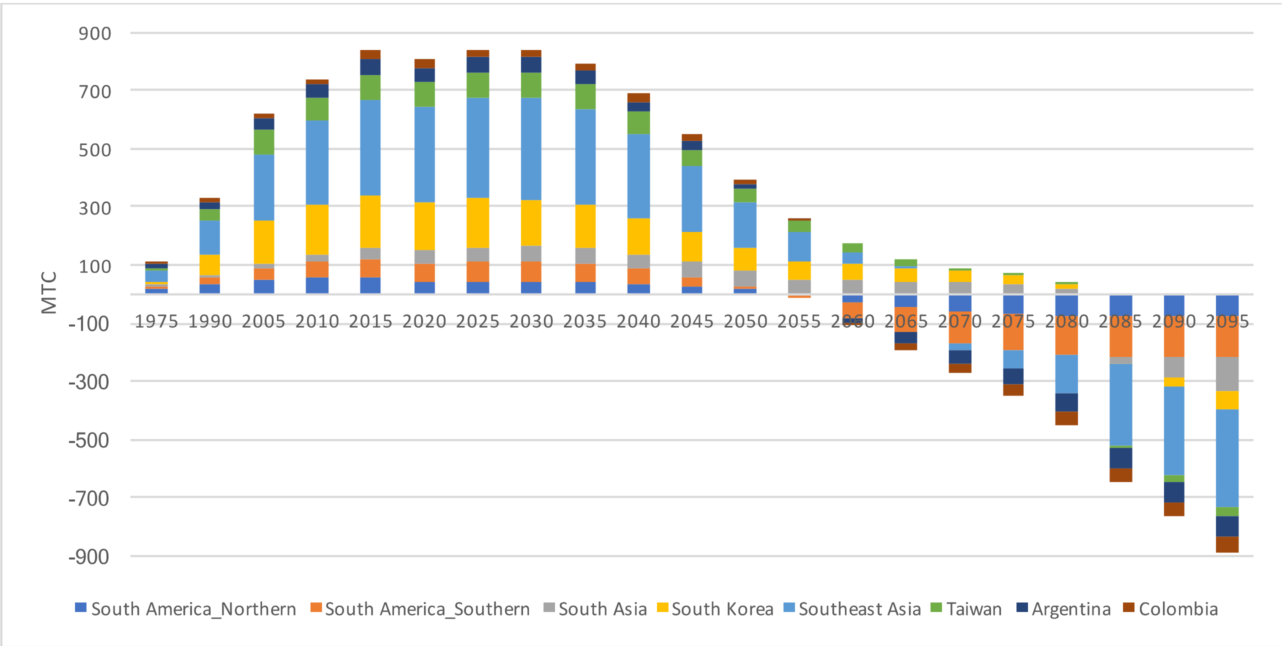

Fig. 9. Emissions in million carbon tons for specific GCAM regions under RCP2.0

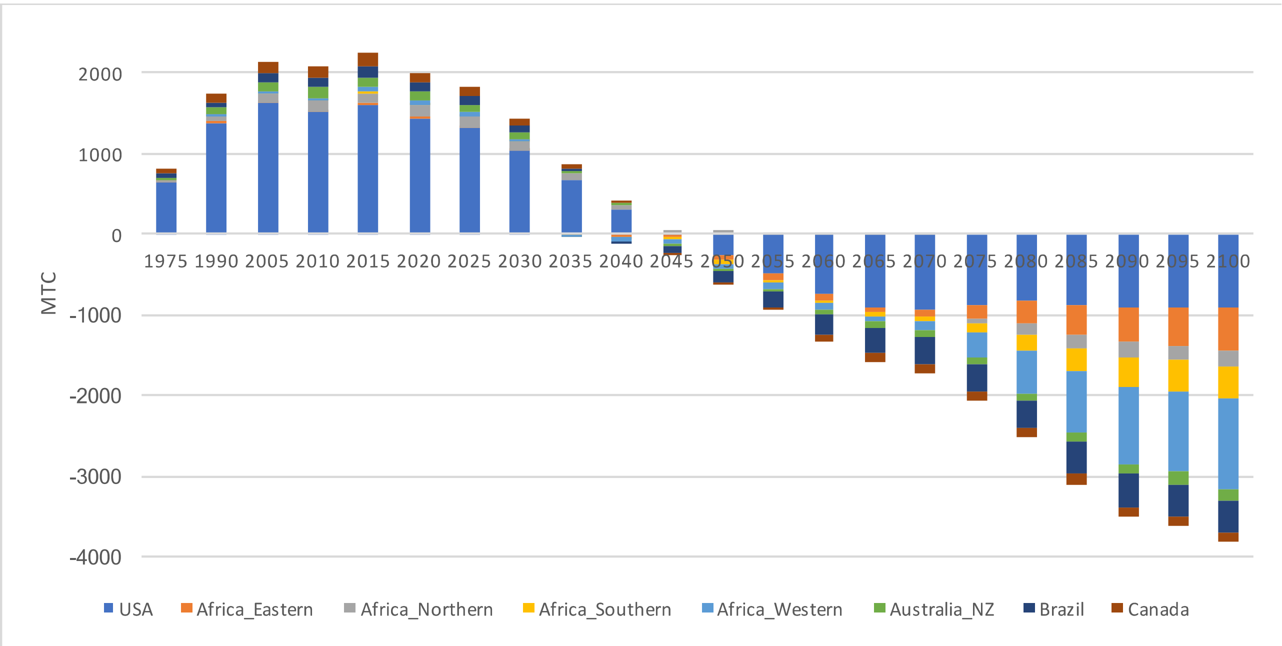

Fig. 10. Emissions in million carbon tons for specific GCAM regions under RCP1.0

2.3. RCP1.0 scenario

The energy system under RCP1.0 demonstrates additional major emissions reduction. In this case, the US (Fig. 10) is expected to show negative emissions at 2050. Its emissions are minimizing locally at 2090 but then they increase and decrease again to demonstrate their minimum at 2100. This behavior is due to arithmetic issues of the software we use, hence in the reality the system observes a firmer performance to a minimum, probably at the end of the century.

Similar for the European countries, as shown in Fig. 11, negative emissions appear earlier than before and emissions demonstrate a local minimum at 2090, which is better expected to appear at once at the end of the century. China requires to have negative emissions also at 2050.

For India, negative emissions appear only after 2065, as shown in Fig. 12. Here it has to be mentioned that substantial time distances in meeting specific patterns such as negative emissions, between countries are usually inapplicable to the

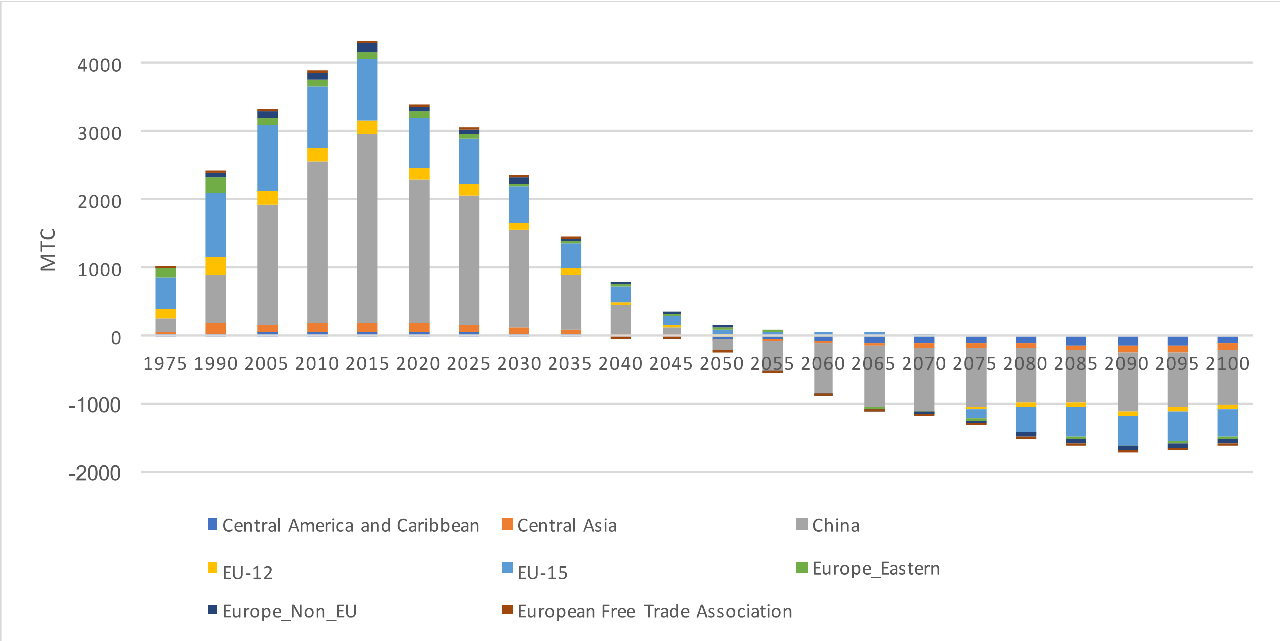

Fig. 11. Emissions in million carbon tons for specific GCAM regions under RCP1.0

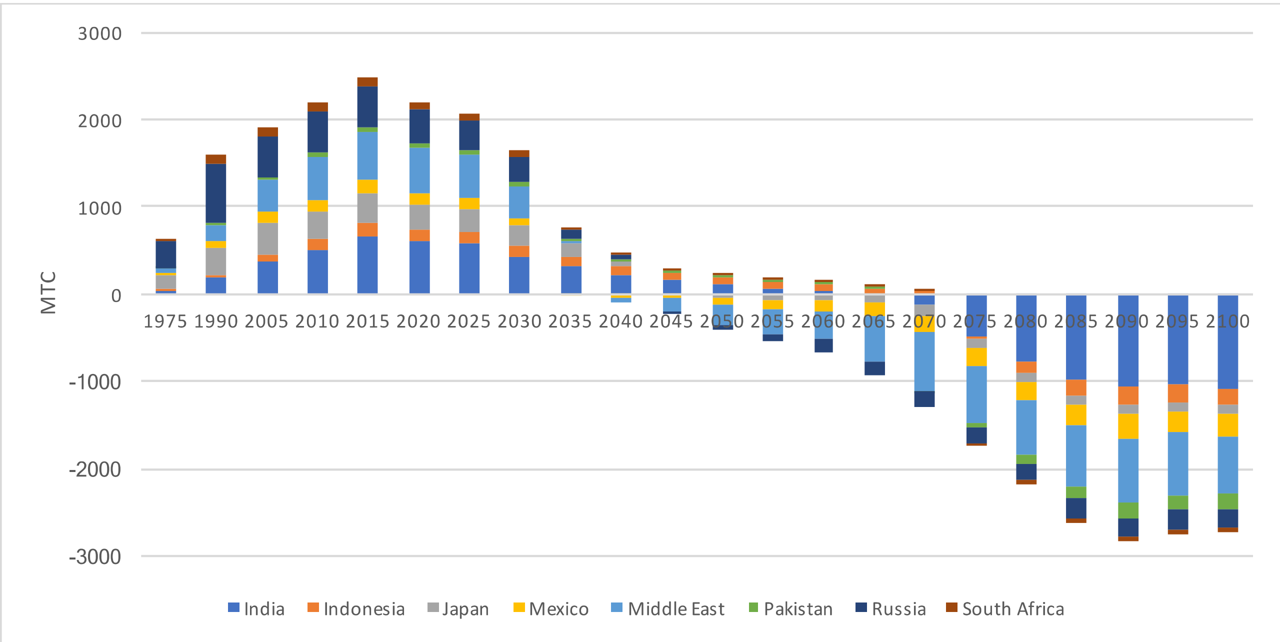

Fig. 12. Emissions in million carbon tons for specific GCAM regions under RCP1.0

reality. When technology is available, it applies globally improving the situation.

For smaller countries, as shown in Fig. 13, emissions follow similar pattern. They demonstrate substantial decrease but their contribution to global emissions is minor. All simulation results are available on Harvard Dataverse [45] and they include additional to the presented data.

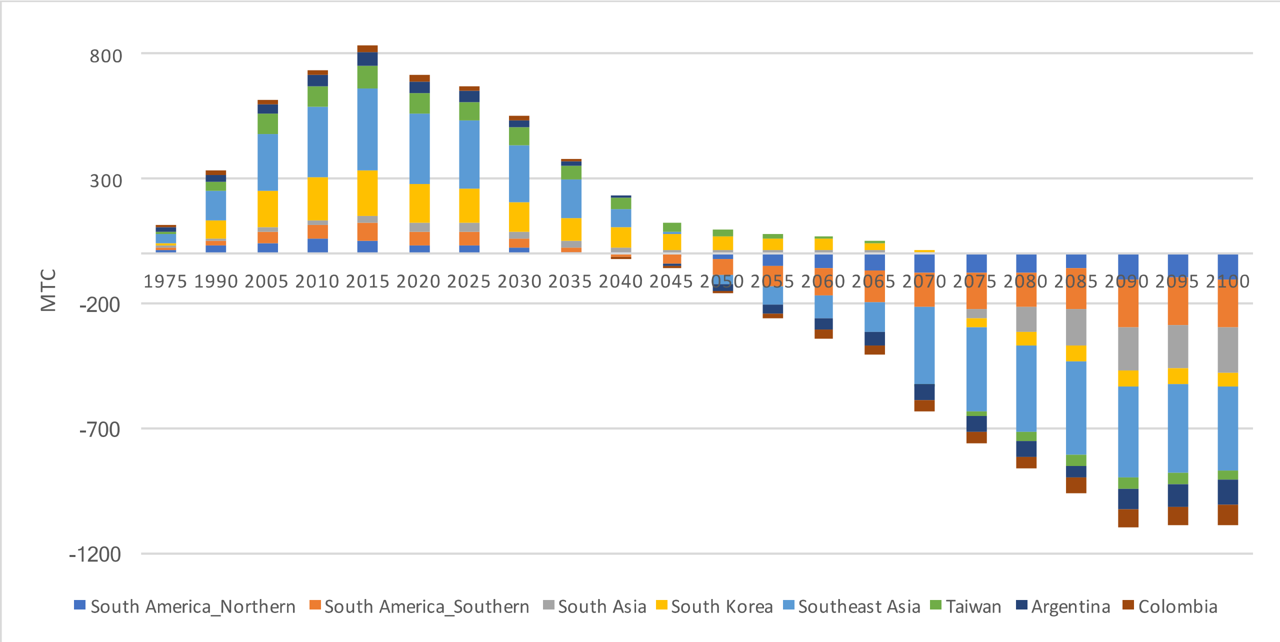

Fig. 13. Emissions in million carbon tons for specific GCAM regions under RCP1.0

3. Conclusion

This paper aims at correlating Paris Agreement with Representative Concentration Pathways (RCPs) over the end of the century, using as starting point the RCP2.6 scenario and consequently proposing and examining pathways that involve substantial decrease of emissions compared to RCP2.6, namely RCP 2.0 and RCP1.0.

The results, through the elaboration of an integrated assessment tool (GCAM), provide useful insights on extended pathways for meeting Paris Agreement targets. This work demonstrates that more ambitious scenarios increase the probability for meeting Paris Agreement targets. Those scenarios are based on stricter projection of RCP2.6 and could correspond to RCPs 2.0 and 1.0. Our findings include the requirement of major negative emissions to be observed. Industrialized and developing countries have substantial contribution, mostly based on their population rather than their economic situation. Developed countries demonstrate their emission minimums before the end of the century, when the rest of the countries decrease steadily their emissions. Our future work on the subject includes improved resolution for each geographic region, if possible to the level of individual countries. This would enhance the robustness of simulated results, as it will produce more realistic representations of local energy systems.

Supplementary Materials

Simulation results are available online on "Harvard Dataverse" at http://dx.doi.org/10.7910/DVN/UFLX1G.

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