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Review

A review of greenhouse gas emission profiles, dynamics, and climate change mitigation efforts across the key climate change players

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A B S T R A C T

The main objective of this study is to analyze and compare greenhouse gas emission profiles, dynamics thereof, and the climate change mitigation efforts of the major players in the global climate change arena, namely the G7 and BRICS countries that are accounting for more than 60% of the world greenhouse gas emissions as in 2017. Given that the energy sector is the major source of the greenhouse emissions in these countries, the framework of sustainable energy development indicators was applied to the comparative analysis. The analysis revealed the differences among the groups of countries in terms of greenhouse gas emission profiles and development trends of these profiles. The convergence of greenhouse gas emission profiles can be noticed between G7 and BRICS countries during 1990–2017 period. Greenhouse gas emissions per capita has decreased in G7 countries and increased in BRICS countries. Energy intensity, economic growth and carbon factor are the main drivers of greenhouse gas emissions per capita growth in both groups of countries. Carbon factor represents carbon intensity of a country's energy sector and is measured by greenhouse gas emissions per unit of total primary energy supply. The impact of carbon factor was least significant among the main drivers in both groups. Energy intensity was the major driver of decrease in greenhouse gas emissions per capita for both groups, however, the economic growth exceeded the contribution of energy intensity in BRICS countries and greenhouse gas emissions have increased in this group during investigated period. The comparative analysis of greenhouse gas emission profiles development trends and the main drivers of these trends in both groups of countries provides important insights in shaping future climate change mitigation policies and developing greenhouse gas emission reduction targets. Due to the high greenhouse gas profiles, low GHG reduction commitments and insufficient climate change mitigation the Perform, Achieve and Trade (PAT) scheme in India efforts in both groups there is danger of postponing implementation of Paris commitments and achieving the 1.5° target. The policies implemented in high ranked countries, like or Integrated Resources Planning in South Africa or measures under Energy efficiency directive in EU can be applied in low ranked countries by providing the substantial contribution to the country's climate targets.

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1. Introduction

The climate change has become an important global issue that is related to energy, economics, environment, and technology. Without taking further actions to reduce the global greenhouse gas (GHG) emissions, global warming is likely to exceed 2 °C above the pre-industrialized levels. Such development would have a huge impact on the world's landscape and sea levels and affect the economic and social development of countries all over the world. Accordingly, it is necessary to identify the paths for GHG emission management in the major emitting countries, which are subjected to the international commitments and national policies. The Group 7 (G7) and BRICS countries account for more than 60% of the world GHG emissions excluding Land Use, Land Use Change and Forestry (LULUCF) as in 2017. These countries present different GHG emission profiles and trends under the climate change mitigation agenda (Climate Transparency, 2018; Climate Action Tracker, 2018).

The G7 is an international group of seven world leading developed countries (Canada, France, Germany, Italy, Japan, the United Kingdom, the United States). The G7 represents more than 60% of the global net wealth and almost 50% of the global GDP. The five leading emerging economies compose BRICS (Brazil, Russia, India, China, and South Africa). The G7 and BRICS countries (except Russia) have ratified the Paris Agreement, and Trump Administration's intent to withdraw from the Paris Agreement creates many concerns in other G7 countries and all over the world. Therefore, the climate change policies and the associated decarbonization actions in those countries are particularly important within the transition towards the low-carbon economy.

The BRICS countries span over the four continents and showed diverse economic, social, political, and cultural characteristics. For instance, South Africa is rich in mineral resources; Russia is rich in fossil energy and other resources; Brazil's economy is based on the agriculture; China's economy is based on manufacturing, whereas India embarks on the development of the service sector. Owing to these differences, their GHG emissions profiles as well vary among themselves.

Only a few studies are comparing G7 and BRICS countries in terms of GHG emissions and climate change mitigation policies. Most of the studies on this issue attempted to facilitate the comparisons among the G7 and BRICS countries by selecting specific issues like economic, environmental, and social performance (Zhou et al., 2012; Santana et al., 2014; Mostafa and Mahmood, 2015), long-term potential energy savings and GHG emissions reduction (Santana et al., 2015; Gil-Alana et al., 2016; Iftikhar et al., 2016), analysis of GHG emission trends (Chang et al., 2016; Chen et al., 2017; Chang and Hu, 2018), without providing a complete picture of the major GHG emitters, including GHG emission trends, their drivers, and policies assessment.

The long-term relationship between energy consumption and gross domestic product (GDP) was analyzed in several studies (Belke et al., 2011; Niu et al., 2011; de Castro Camioto et al., 2016). The mutual impacts between GDP and energy demand were revealed (Chen et al., 2017; Chang et al., 2016). Tu et al. (2016) and Chang and Hu, 2018 showed the difference in energy-decoupling rates in the G7 and BRICs, however, without the assessment of policy impacts.

Ghouali et al. (2016) found that energy consumption, foreign direct investments (FDI), and economic development have direct impact on the GHG trends in the BRICS countries. Tugcu and Tivai (2016) tested the relationship between energy consumption and total factor productivity growth in the BRICS countries; Chang (2015a,b), Pao and Tsai (2011), and Shahbaz et al. (2015) tested the Environmental Kuznets Curve hypothesis for BRICS, and both obtained contradicting results among the countries. Azevedo et al. (2018) analyzed the GHG emissions for the BRICS countries by considering lagged emission and the contemporaneous GDP as the regressors, however, the other drivers of the GHG emissions are not being taken into account in this analysis.

The (groups of) G7 and BRICS countries have been covered as well in the research that focused on the other countries. Zhou et al. (2012) found that the OECD countries show better carbon emission performance and integrated better energy-carbon performance than the non-OECD countries. Li and Lin (2013) investigated the global convergence in per capita GHG emissions and GDP per capita relationships by considering data for 110 countries. Chen et al. (2013) evaluated the economy-wide impacts of cutting CO_2 emissions on the Brazilian economy. The impact of GDP, FDI, energy efficiency, and renewable energy consumption on the GHG emissions in different countries was analyzed by Al-mulali (2012), Robalino-López et al. (2015), Liobikiene and Butkus (2018). The literature on the decomposition of the GHG emission change mostly focuses on the BRICS countries, e.g., China (Wu et al., 2005; Wang et al., 2005; Xu et al., 2017) and India (Paul and Bhattacharya, 2004) without linking the GHG emission to the implemented climate change mitigation policies.

The contemporary literature focuses less on the analysis of possible realization of the emission mitigation targets. The largest part of literature focuses on China and its emission reduction targets for 2020 (Koo et al., 2014; Liu et al., 2014; Hao et al., 2015). Yi et al. (2016) combined scenario analysis and decomposition approach to show that the carbon emissions reduction target can be fulfilled by 2020. The results showed that the economic output, energy structure, and population are the most important drivers behind the CO_2 emission change. Using the production function, Lin et al. (2017) analyzed the Brazilian challenges in achieving a cleaner energy system due to switching from petroleum to cleaner energy (electricity).

The literature review indicated that most of the earlier studies dealt with resource productivity and energy-environment-economy nexus in the BRICS and G7 countries. The differences in the GHG emission profiles in BRICS and G7 countries have not been analyzed in detail. In addition, most of the studies applied econometric models without presenting the differences between a group of countries and implication of these differences for their climate change mitigation efforts in a simple and transparent way. Therefore, there is a need for comparison of two blocks of countries (G7 and BRICS) in terms of GHG emissions profiles and GHG reduction policies to define what is the specific relevance of these two groups in the climate change mitigation context and how this would incorporate into the understanding of global climate change and mitigation dynamics.

1.1. The main hypotheses of this study are the following

- The major global GHG emitters have different GHG emission profiles that are linked to the difference in the economic development level, economic and primary energy supply structure and climate change mitigation policies in place.
- The role of the G7 and BRICS countries is changing global climate arena due to the converging trends in the GHG emission profiles that are linked to the fast economic development of BRICS countries and strict climate change mitigation policies in G7 countries.
- The majority of key climate players will not be able to implement their Paris agreement targets due to fast economic growth, the weak climate change mitigation efforts and policies in the energy sector and deforestation.

The main objective of this study is to develop the framework of indicators and apply it for the comparative analysis of the GHG emission profiles, their development trends, and GHG reduction efforts of the major players in the global climate change arena, i.e., G7 and BRICS countries. This allows testing the hypotheses and understanding and comparing the main drivers of GHG emissions and necessary climate change mitigation efforts and challenges in the global climate change mitigation arena. The comparative assessment approach was applied, which consist of the following steps: GHG emission profiles of the countries were defined; the trends of GHG emission profile development are compared and discussed by identifying the similarities and differences and its main reasons; the critical review of the implemented and set up climate change mitigation policies and implications of Paris agreement targets were assessed. The strength of the comparative assessment approach is its simplicity and application of both qualitative analysis and quantitative data in the analysis. This approach allows to track the results that were achieved by countries in the GHG mitigation as well as to analyze the main drivers of these achievements. The limits are mainly linked to the subjectivity of the applied approach.

The paper is organized as follows: Section 2 presents the review of literature on the GHG profiles and assessment of the climate change mitigation policies, which result in the frameworks that are comprising sustainable energy indicators; Section 3 presents results: the GHG emission profiles and their dynamics for G7 and BRICS countries by applying sustainable energy indicators that are linked to the climate framework and assessment of GHG emissions reduction commitments and progress that is achieved in G7 and BRICS countries; Section 4 provides discussion of results in comparison with other studies including policy implications; Section 5 concludes.

2. Method for assessment of GHG emission profiles and policies

2.1. Literature review

The differences between countries can be described by the indicators that depict the natural circumstances and socio-economic conditions of countries in relation to the possibilities of reducing GHG emissions. The comparison between actual and desirable values of the indicator allows quantifying the progress towards GHG targets (Hardi and Barg, 1997; Scheller, 1999). The well-developed indicator systems can facilitate the comparisons in complex situations by condensing large amounts of information into low-dimensional aggregates (Bossel, 1999). However, the initial set of indicators remains the key issue in facilitating the analysis of GHG emission profiles.

Energy is the major factor input in the economy. At the same time, the increasing fossil/non-renewable energy use drives the GHG emissions up, especially carbon dioxide (CO_2) emission. CO_2 remains the primary chemical of greenhouse gas emissions (GHG) and accounts for 76% of the total anthropogenic GHG emissions. Fuel combustion induces about 90% of the anthropogenic carbon dioxide emission (IPCC, 2007). The desire for combating climate change via improvements in the energy efficiency and an increase in the share of renewables had an impact on the policies in the developing countries. Specifically, these countries seek to reduce the GHG emissions (Pao and Tsai, 2010; Tsai, 2010) without damping economic growth. Therefore, they should increase the investments in cleaner (renewable) energy supply and energy efficiency, which are the main drivers of sustainable energy development (Neves and Leal, 2010). Therefore, it is necessary to develop indicator systems for the assessment of GHG emission profiles, which guides policy makers by supporting decisions on the investments in renewable energy, industrial modernization, and energy efficiency improvements.

As the main focus of this paper is the assessment of GHG emission profiles of major GHG emitters and their progress towards GHG commitments, given the importance of fuel combustion sector input in the total GHG emission of these countries, the frameworks of sustainable energy indicators can provide a well-based conceptual framework to ensure the link between the indicators and the indicated fact, which would allow presenting specific policy guidelines for the policy-makers in energy and climate change mitigation field (Hák et al., 2016).

There were many initiatives in the past three decades to develop energy or sustainable energy indicators' systems and apply them. International institutions (IAEA, 2005; United Nations, 2012; Ecological Institute, 2011) have developed energy indicators frameworks for assessment of countries trends towards sustainable energy development. European Union institutions (Eurostat, 2015, 2018; European Commission, 2017a, 2018) have proposed their indicators frameworks for energy policies and strategies monitoring. Other energy indicators systems (Finland Future Research Centre, 2007) present limited number of indicators for linking energy and climate issues.

For selecting the most important energy indicators that are linked to the climate change by taking into account availability of data supplied by International organizations, several frameworks of indicators were analysed and considered (IAEA, 2005; Climate Transparency, 2018; Climate Action Tracker, 2018). In this study, as a background for developing a framework of indicators, the indicators framework of Energy Indicators for Sustainable Development (EISD) was applied (IAEA, 2005). Other analyzed frameworks applied just several indicators from this comprehensive framework (Hirschberg et al., 2007; Onat and Bayer, 2010; Neves and Leal, 2010) without presenting clear linkages between indicators. EISD is the only energy indicators framework that is providing clear interlinkages between state, driving force, and policy indicators, which are relevant for this study. The social dimension is underrepresented in this set (Kemmler and Spreng, 2007); nevertheless, the proposed indicator system covers the most important economic and environmental sustainability dimensions that are linked to the climate change in energy sector, which allows providing a comprehensive evaluation of sustainable energy development process, including climate change mitigation efforts. There are 30 indicators that are classified into three dimensions (social, economic, and environmental). These are further broken down into 7 themes and 19 sub-themes (IAEA, 2005). Energy Indicators for Sustainable Development (EISD) framework that were developed by the IAEA are outlined in Table 1.

The indicator system that is proposed by IAEA (2005) considers air, water, and land use and pollution in order to quantify the effects of the energy production and consumption. The social dimension is related to the energy accessibility and affordability as well as safety considerations. The economic dimension captures the energy use and production characteristics along with the energy security issues.

2.2. *Framework of sustainable energy indicator linked to the climate change*

In order to define the GHG emission profiles in G7 and BRICS countries, the authors of this article chose the indicators that are covering economic activity and environmental issues that are linked to climate change mitigation that are applied in several studies (IAEA, 2005; Climate Transparency, 2018; Climate Action Tracker, 2018) and supported by the International Energy Agency and other international institution data sets. The resulting set of sustainable energy development indicators that are linked to the climate change mitigation framework is presented in Table 2.

As one can see from Table 2, some sustainable energy development indicators, linked to the climate change, have been applied for setting GHG emission reduction commitments.

EC1 indicator represents Gross Domestic Product (GDP) per capita and is an aggregate indicator to measure the total output of the country's economy that is relevant to its population. It gives an indication of the strength of economic activity in a country and the overall well-being of the society.

EC2 indicator represents the Total Primary Energy Supply (TPES) per capita and is an indication of the aggregate energy consumption of the country. Although high value of this indicator usually means high standard of living and is considered an indicator of the urbanization of the society; it may as well mean an energy-inefficient society.

EC3 indicator represents the energy intensity of GDP. It can be assessed by TPES/GDP. It is widely known as Energy Intensity and is the most popular energy efficiency indicator. Since it signifies the energy requirements to generate a unit of national input, it paints a collective picture on how efficient is the economy of a country. There are many studies in literature that are examining and emphasizing the relationship between the GDP of different countries and their energy consumption, CO_2 emissions by applying Environmental Kuznets Curve (EKC) hypothesis (Chang, 2015a,b; Robalino-López et al., 2015). Moreover, these studies argue that as the energy intensity of a country increases during its industrialization phase, it declines in the post-industrialization phase as the service gradually replaces the manufacturing. The high differences in this indicator among the countries are mainly due to the diversity of the production structures and the concentration on high added value activities and industries in comparison to the energy intensive industries in other countries. However, these values should be used cautiously when drawing conclusions, regarding the structure of the economies in question. For example, Jordan has a higher TPES/GDP than Kuwait, though Kuwait with 2.46mill. Inhabitants consumes about 7 times more energy than Jordan, having

Table 1
Energy Indicators for Sustainable Development (EISD) framework dimensions, themes, and sub-themes.

Social dimension	Economic dimension	Environmental dimension
Equity	**Energy use and production pattern**	**Atmosphere**
Accessibility	Overall income	Climate change
Affordability	Overall energy use	Air quality
Disparities	Overall energy production	**Water**
Health	Energy supply efficiency	Water quality
Safety	Energy production and end use	**Land**
	Diversification	Soil quality
	Energy prices	Forests
	Security	Solid wastes
	Energy Imports	
	Strategic fuel stocks	

Source: (IAEA, 2005)

Table 2
Sustainable energy development indicators that are linked to the climate change mitigation.

Code	Indicator	Units of measurement	Target value under commitment
Economic indicators			
EC1	Overall income per capita	GDP per capita at PPP, USD 2010	
EC2	Overall use of energy	TPES per capita– kgoe/capita	
EC3	Primary energy intensity	TPES per GDP - toe/USD 2010	
Environmental indicators			
EN1	GHG emissions	GHG emissions from fuel combustion -Mt CO_2eq.	+
EN2	Carbon intensity of TPES	kg CO_2eq./toe	
EN3	Carbon intensity of GDP	ton CO_2eq./USD 2010	+
EN4	Share of RES in final energy consumption	%	+
EN5	GHG per capita	CO_2eq./cap	

Source: created by the authors

5.44 mill. Inhabitants. This is mainly due to the fact that a large share of the GDP in Kuwait is a direct result of exporting crude oil and is not due to the real economic activities. The same could be said for most of the oil-exporting countries.

EN1 indicator represents the total GHG emissions from the fuel combustion sector. The CO_2 equivalent emissions of all GHG emissions from fuel combustion are summed and applied as the main indicators of the climate change.

EN2 indicator represents the carbon intensity of the total primary energy supply (TPES) expressed by Greenhouse gas emissions and total energy supply ratio (GHG/TPES), what is commonly known as the carbonization index, which is dependent on the share of the fossil fuel in the TPES and the composition of the fossil fuel mix. The target is always to achieve the lower values of the carbonization index. The high values of the carbonization index in most countries are due to the nearly total dependence on the fossil fuels, namely petroleum products and natural gas, and the negligible contribution of other energy sources such as renewable and nuclear energy.

EN3 represents the carbon intensity of the economy that is expressed by Greenhouse gas emissions and Gross Domestic Product ratio (GHG/GDP). The carbon intensity of GDP is an important indicator to measure the efficiency of energy consumption and carbon content of the energy supply in the country. It is as well called the carbon economic efficiency indicator.

EN4 represents the share of renewables in total final energy consumption. Many countries have set their obligations to promote the use of renewables by setting targets to increase the share of renewable energy sources (RES) in their final energy consumption.

EN5 represents GHG/capita. This indicator together with the total GHG emissions and GHG emissions per $1 GDP at purchasing power parity (PPP) were applied to measure Millennium development goals (Goal 7. Ensure environmental sustainability; Target 7A: Integrate the principles of sustainable development into country policies and programs and reverse the loss of environmental resources; Indicator 7.2 Carbon dioxide emissions, total, per capita and per $1 GDP (PPP)). This indicator is as well called the carbon life style efficiency indicator.

2.3. Methods of the study

The analysis of GHG profiles of the G7 and BRICS countries was performed in this paper based on the sustainable energy development indicators that are linked to the climate change framework and comparative assessment approach. The applied methodology consists of the following steps: GHG emission profiles of countries were defined by applying sustainable energy indicators that are linked to climate change, the trends of GHG emission profiles and the main drivers of these are compared and discussed by identifying the similarities and differences and the main reasons for it; the critical review of the implemented climate change mitigation policies and implications of Paris agreement targets were assessed. The methodology is presented through the flowchart in Fig. 1.

The main strength of the comparative assessment approach is its simplicity and application: both qualitative analysis and quantitative data in the analysis. This approach allows tracking the results that were achieved by the countries in the GHG mitigation as well as to analyze the main drivers of these achievements. The limits are mainly linked to the subjectivity of the applied approach. The applied methodology can be easily replicable and used for the comparative assessment of GHG emission profiles and their drivers in other countries.

Fig. 2 illustrates the linkages between sustainable energy indicators that are linked to the climate change mitigation that is selected for this study. The relevant policy actions are identified and represented as response actions to the targeted indicators. The numbers of indicators in Fig. 2 refer to the identification numbers of the indicators that are listed in Table 2. Indicators are as well grouped according to the policy areas (energy efficiency improvement, promotion of renewables, climate change). Some indicators of this framework, like in the EISD framework (IAEA, 2005), are the direct driving force indicators, indirect driving force indicators, and state indicators. In Fig. 2, this is represented by the geometrical figures (triangle, ellipse, and quadrat).

All the selected indicators can be connected to each other via a chain of mutual impacts by seeking to develop a comprehensive policy framework for linking GHG emission profiles with the implemented climate change mitigation-related efforts and tracking various interacting policy measures that are targeting relevant indicators. The last indicator in this framework is greenhouse gas emission per capita, as all the policies (targeting energy efficiency improvements, promotion of renewables, low carbon fuels, etc.) have a positive impact on the greenhouse gas emission reduction and carbon lifestyle efficiency in the end.

As one can see from Fig. 2, there are state indicators, direct driving force, indirect driving force indicators, and response actions that are having an impact on the indicators. Indicators that are representing economic and environmental area as well are grouped based on the policy areas: energy efficiency, renewables, and GHG emissions.

The GHG emissions from the energy sector, GHG/capita, GHG/GDP, GHG/total primary energy supply are final environmental state indicators in a chain of mutual impacts and are used to assess the GHG profiles of countries. The direct driving force of the GHG emissions is the energy intensity of the GDP. The carbon intensity of the final energy supply depends on the gross inland energy supply mix, electricity generation mix, and the share of renewables in the final energy consumption, in the electricity generation, heating,

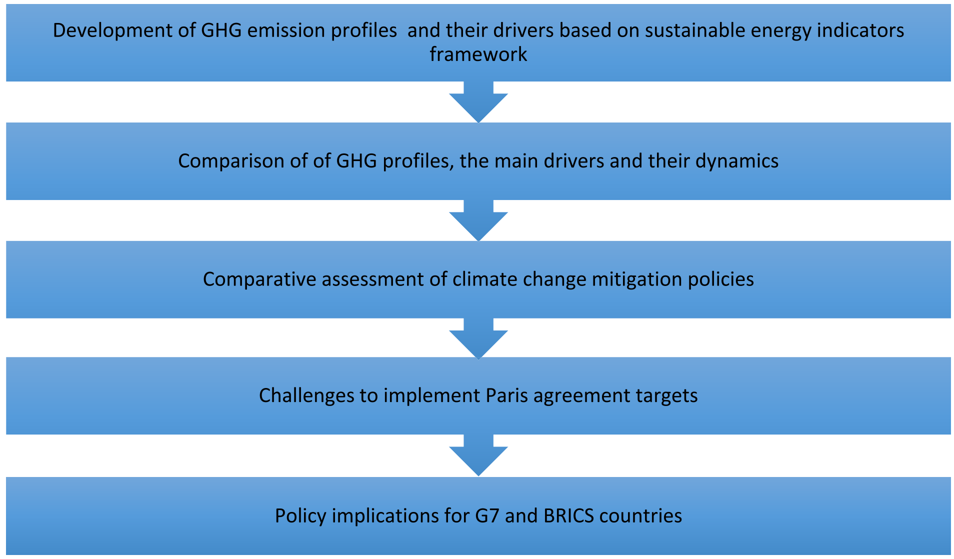

Fig. 1. Methodology of the study.

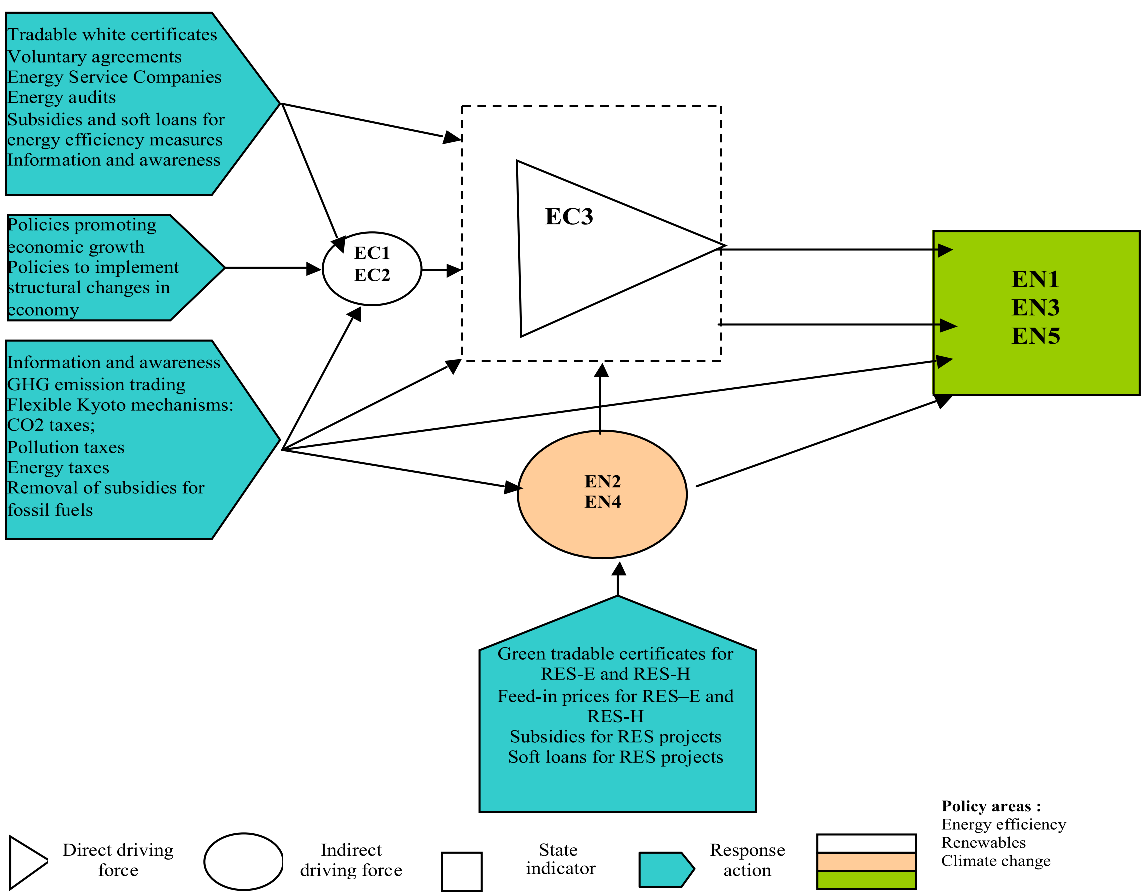

Fig. 2. Linkages between the selected indicators and relevant policy actions on the selected indicators.
Source: created by the authors, based on (IAEA, 2005)

and cooling, and transport fuels, which are the main indirect driving force indicators of the GHG emissions. The GDP/capita, energy consumption per capita, energy efficiency of energy supply system, and energy import dependency are indirect driving force indicators that have an impact on the energy intensity and the GHG emission profiles of the countries.

3. Results

3.1. Dynamics of sustainable energy development indicators linked to the climate in the G7 and BRICS countries

The dynamics of sustainable energy development indicators that are linked to climate in the G7 and BRICS countries represent the changes of the GHG emission profiles and their drivers in the selected countries. The selected indicators framework (Fig. 2) captures the most important economic growth, energy consumption and economic structure features, and corresponding GHG emission.

3.1.1. Driving force indicators of the GHG emissions

There are direct and indirect driving force indicators of the GHG emissions (Fig. 2). The direct driving force indicator is the energy intensity of the GDP. The carbon intensity of the final energy supply depends on the gross inland energy supply mix, electricity generation mix, and the share of renewables in the final energy consumption, in the electricity generation, heating, and cooling, and transport fuels, which are main indirect driving force indicators of the GHG emissions. The GDP/capita, energy consumption per capita, energy efficiency of energy supply system, and energy import dependency are as well indirect driving force indicators of the GHG emissions.

E1 indicator that is expressed by the GDP/capita adjusted to the PPP, which shows the achieved economic development level of the G7 and BRICS nations. In Fig. 3, the GDP per capita that is adjusted to the PPP dynamics in the G7 and BRICS during 1990–2016 is presented.

As one can see from Fig. 3, all the countries achieved significant economic growth during 1990–2015. The economic crisis of 2008 had an impact on the GDP/capita decline in almost all the investigated countries, except for China and India.

TPES/capita represents the overall energy consumption level in the country; it is linked to the GDP/capita and is an important driver of the GHG emissions as well. In Fig. 4, the dynamics of TPES/capita in the G7 and BRICS countries during 1990–2016 is presented.

As one can see from Fig. 4, BRICS countries had significantly lower TPES/capita, compared with G7 countries, during all the investigated period. Only Russia distinguishes from the other BRICS countries with high TPES/capita ratio, which even exceeded the EU average. The increase in the TPES/capita can be noticed in India, Brazil, and China during 1990–2016.

The primary energy intensity of GDP adjusted to the PPP, which is the most important indicator of the energy efficiency in the country and the main driver of the GHG emissions from the fuel combustion sector. The decline in this ratio represents the level of decoupling of economic growth from the energy consumption and indicating sustainable development path of the country. In Fig. 5, the dynamics of primary energy intensity of GDP adjusted to the PPP in G7 and BRICS countries during the period of 1990–2016 is presented.

As one can see from Fig. 5, the EU member states were leaders in low energy intensity of GDP during the investigated period. In 2016, Russia had the highest energy intensity of GDP (0.22 toe/thousand USD, 2010), though, since 1990, this indicator has declined significantly in Russia, but this decline was linked more to the economic recession than to the implemented energy improvement measures.

The share of renewables in total final energy consumption has a direct impact on the carbon intensity of TPES and carbon intensity of GDP and is an important driver of GHG emissions in the country. In Fig. 6, the dynamics of the share of renewables in the final energy consumption in the G7 and BRICS countries from 1990 to 2016 are given.

As one can see from Fig. 6, South Africa and Brazil were the countries with the highest share of renewable energy sources in the final energy consumption. Canada is the leader among the other G7 countries in terms of penetration of renewables.

3.1.2. Dynamics of GHG profiles

The GHG emission profiles are expressed by GHG emissions, carbon intensity of the total primary energy supply, carbon intensity of the GDP and GHG emissions per capita. In Fig. 7, the dynamics of GHG emissions in the G7 and BRICS countries from 1990 to 2016 are given.

As one can see from Fig. 7, the GHG emission levels are very different between the analyzed countries, as these countries are of different size in terms of population, economy, and achieved economic development level. China distinguishes among all the countries with a high increase of GHG emissions during the

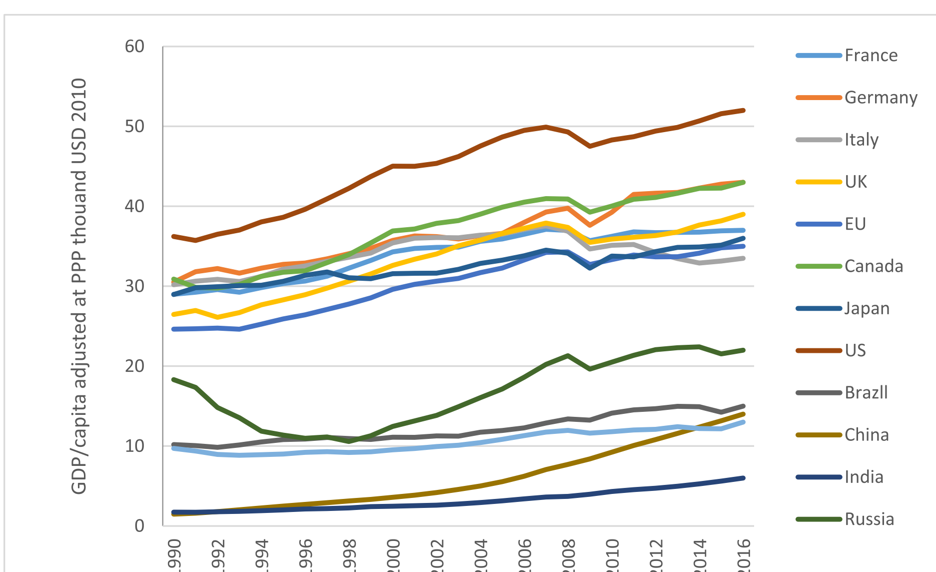

Fig. 3. The dynamics of GDP per capita adjusted to the PPP in G7 and BRICS countries during 1990–2016.
Source: created by the authors, based on the data from the World Resource Institute, CAT (Climate Data Explorer database): http://cait.wri.org/historical/Country/

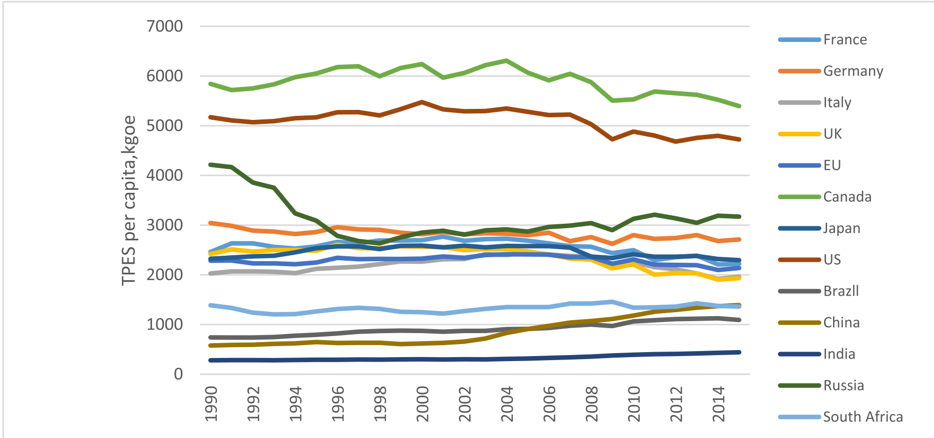

Fig. 4. The dynamics of TPES/capita in G7 and BRICS countries during 1990–2016.
Source: created by the authors, based on the data from the World Resource Institute, CAT (Climate Data Explorer database): http://cait.wri.org/historical/Country/

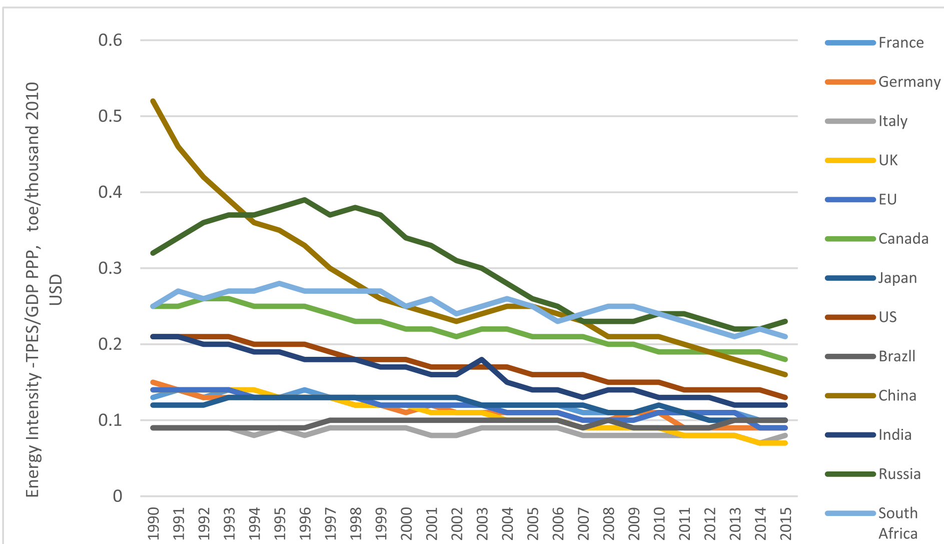

Fig. 5. The dynamics of primary energy intensity of the GDP that is adjusted to the PPP in G7 and BRICS countries during 1990–2016.
Source: created by the authors, based on data from the World Resource Institute, CAT (Climate Data Explorer database): http://cait.wri.org/historical/Country/

investigated period.

The carbon intensity of the total primary energy supply, expressed by the GHG/TPES or carbonization index, represents the composition of the fossil fuel mix in the country. The decline in this indicator as well shows the decoupling of energy consumption growth from the GHG emissions growth and indicates sustainable development path. In Fig. 8, the dynamics of Carbon intensity of TPES in the G7 and BRICS countries from 1990 to 2016 are given.

As one can notice from Fig. 8, in China, Brazil, Russia, and Canada, the carbon factor or carbon intensity of TPES was increasing during 1990–2016. In EU member states (G7 member), carbonization index was declining during the same period.

The carbon intensity of the economy is expressed by the GHG/GDP measure efficiency of energy consumption and carbon content of energy supply in the country and is an important driver of the GHG emissions. In Fig. 9, the dynamics of Carbon intensity of the GDP that is adjusted to the PPP in the G7 and BRICS countries from 1990 to 2016 is given.

As one can see from Fig. 9, the carbon intensity of GDP has declined during the investigated period in all the analyzed countries.

GHG/capita is a headline indicator expressing the overall GHG profile of the country. As in the case of TPES/capita, the developed nations of the G7 countries distinguish with high TPES and GHG per capita rates due to the lower size of population and high economic development and life standard level. In Fig. 10, the dynamics of GHG/capita in the G7 and BRICS countries during 1990–2016 is presented.

As one can see from Fig. 10, the highest GHG/capita was in the US and Canada during all the investigated period; however, they were decreasing from 2008. The lowest GHG/capita during all the investigated period was in India and Brazil, followed by China; however, during the investigated period, GHG per capita has increased in China (6.59CO_2eq./capita) and reached the EU average level (7.11 CO_2eq./capita) in 2016.

3.2. Comparative assessment results of GHG emission profiles and their development

The GHG emission profiles of G7 and BIRICS countries in 2016 are provided in Fig. 11. The GHG/capita is indicated on X axis and GHG/TPES is plotted on Y axis. The size of the bubbles represents

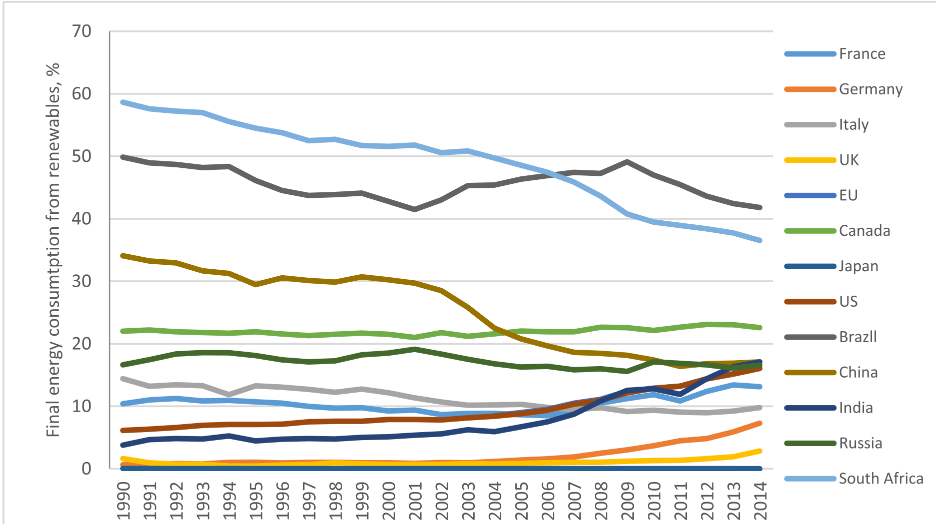

Fig. 6. The dynamics of the share of renewables in the final energy consumption in G7 and BRICS countries from 1990 to 2016.
Source: created by the authors, based on the data from the World Resource Institute, CAT (Climate Data Explorer database): http://cait.wri.org/historical/Country/

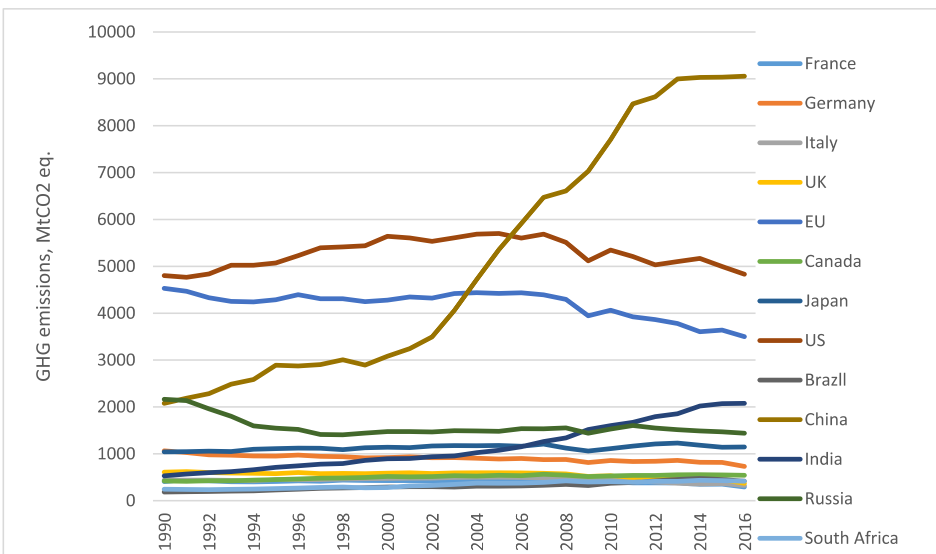

Fig. 7. The dynamics of GHG emissions in the G7 and BRICS countries from 1990 to 2016.
Source: created by the authors, based on the data from the World Resource Institute, CAT (Climate Data Explorer database): http://cait.wri.org/historical/Country/

the GHG/GDP of countries.

As one can see from Fig. 11, France and Brazil distinguishes with the lowest GHG emission profiles. China and South Africa distinguishes with very high carbon factor (carbon intensity of total primary energy supply) and carbon intensity of GDP. Russia, Canada and US are characterized by high GHG emissions per capita and high carbon intensity of GDP. EU member states have average GHG emissions per capita and average carbon intensity of primary energy supply followed by average carbon intensity of GDP.

In order to compare BRICS and G7 countries in terms of their GHG profiles and climate change mitigation efforts we perform a comprehensive ranking. In regards the GHG profiles, we consider the levels for 2017 along with the trends for 2012–2017. The climate change mitigation policies in BRICS and G7 countries were assessed by using data from Climate Transparency (2018) and Climate Action Tracker (2018). The ranking of countries is provided in Table 3.

The scoring of GHG profiles and GHG development trends is based on five-point scale (where 1 indicates low performance and 5 represents high performance). As regards the levels of 2017, high performance is related to the lowest levels of GHG profiles in term of energy use per capita, GHG emissions per capita, energy intensity, carbon intensity of GDP and carbon intensity of energy supply, the highest levels of the share of renewables in energy supply and GDP per capita levels. For GHG profiles development a high performance implies high reduction during 2012–2017.

The highest ranking country in terms of GHG mitigation achievements and efforts is the UK with the EU, France, Germany, Brazil and India being ranked behind (Table 3). Russia is ranked as the worst performing country having the lowest score, with Canada and US being ranked slightly above. Japan, China and India fall in the middle of the ranking.

The highest ranking country in terms of GHG profile considering the levels of 2017 is Brazil having low GHG and TPES, GHG/TPES and

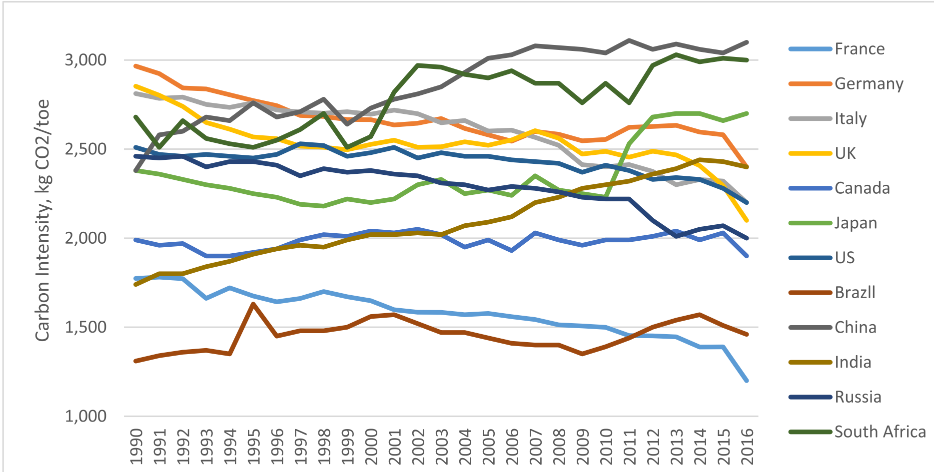

Fig. 8. The dynamics of Carbon intensity of TPES in the G7 and BRICS countries from 1990 to 2016.
Source: created by the authors, based on the data from the World Resource Institute, CAT (Climate Data Explorer database): http://cait.wri.org/historical/Country/

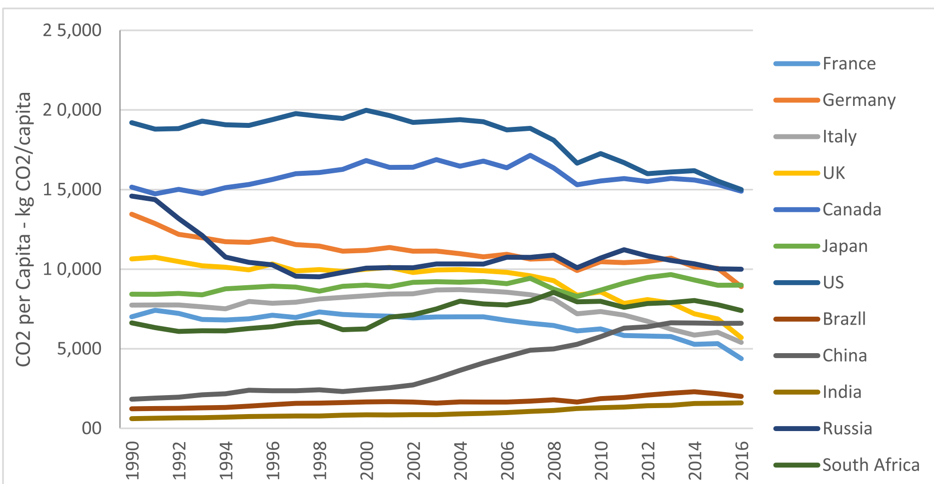

Fig. 9. The dynamics of Carbon intensity of GDP adjusted to the PPP in the G7 and BRICS countries from 1990 to 2016.
Source: created by the authors, based on the data from the World Resource Institute, CAT (Climate Data Explorer database): http://cait.wri.org/historical/Country/

high share of RES in total primary energy supply. It is followed by the UK, Italy, EU and Germany. Russia, South Africa, China and Canada are ranked as countries having the worst GHG profile for 2017. India, Japan, France are in the middle of ranking based of GHG profiles (Fig. 12).

The best performing countries based on the development trends of GHG profiles are the UK, EU, Italy, and China. At the other end of spectrum, the worst performing countries are Brazil, South Africa, and Canada. Italy, France, Russia, Japan, US are middle-ranked countries (Fig. 13). The ranking of countries based on climate change mitigation policies in place is provided in Fig. 14.

The analysis of GHG emission profiles of the major GHG emitters showed that all the G7 countries distinguish with high GHG/capita, significantly over the world average; however, the trends of decline can be noticed. In BRICS countries, having lower GHG emission per capita levels, the opposite trend of GHG emission per capita increase can be noticed. The variations in the carbonization index between BRICS countries are not as prominent as they are for the energy intensity, GHG emissions per capita, and GHG/GDP.

3.3. GHG reduction policies and commitments in the G7 and BRICS countries

In 1990, the G7 countries produced about 30% of the world's GHG emissions, including Land-Use, Land-Use Change, and Forestry (LULUCF) emissions, or 34.4%, excluding LULUCF. In 2014, G7 group was responsible for 21.5% of the total GHG emissions, including LULUCF, or 23.19%, excluding LULUCF (Table 4). However, during 1990–2014, the total GHG emissions in G7 in the total GHG emissions have reduced dramatically.

Since 1990, the BRICS countries' emissions have doubled (Table 4). As a group in 1990, the BRICS produced about 26.8% of the world's greenhouse gas (GHG) emissions, including Land-Use, Land-Use Change, and Forestry (LULUCF) emissions, or 27%, excluding LULUCF. In 2014, the BRICS countries were responsible for 38.3% of the total GHG emissions, including LULUCF, or 41%, excluding LULUCF.

The situation has changed insignificantly since 2014. Based on newest available information in 2017 the share of BRICS and G7 in

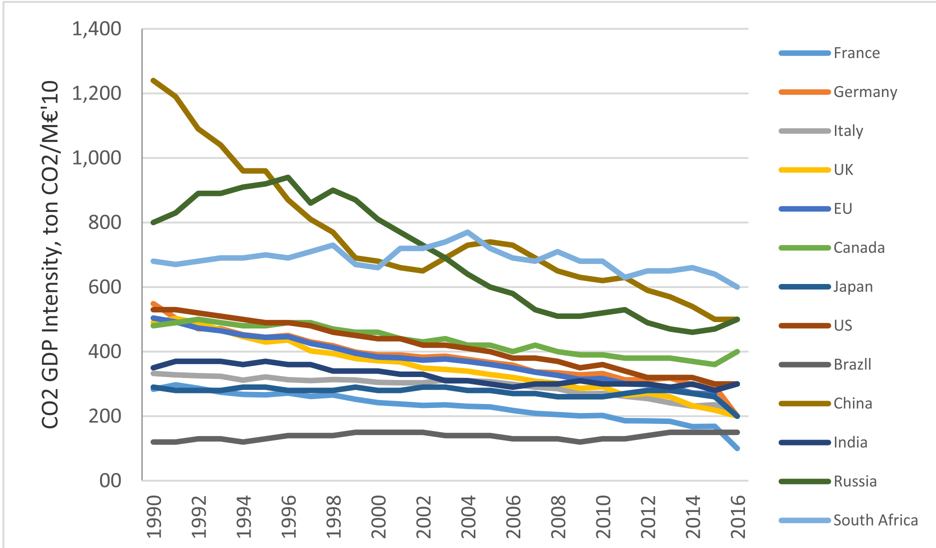

Fig. 10. The dynamics of GHG/capita in G7 and BRICS countries during 1990–2016.
Source: created by the authors, based on the data from the World Resource Institute, CAT (Climate Data Explorer database): http://cait.wri.org/historical/Country/

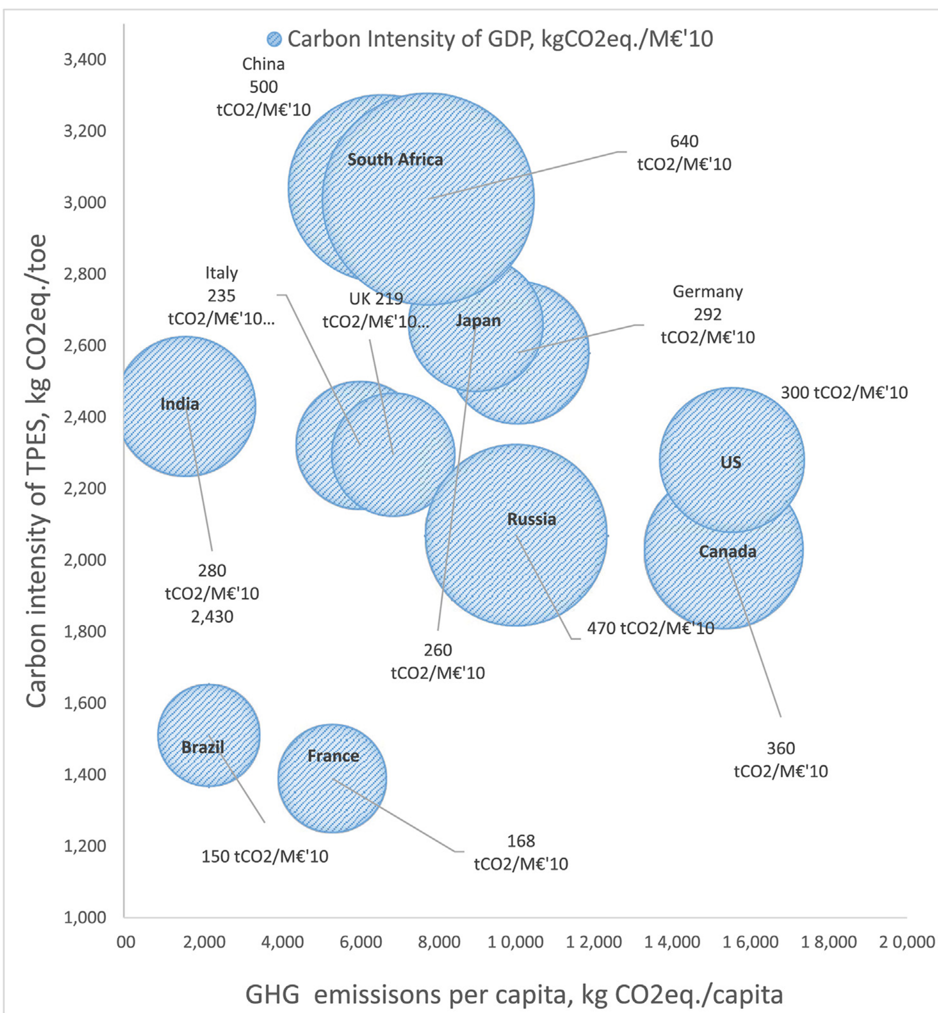

Fig. 11. The GHG profiles of G7 and BRICS countries in 2017.
Source: created by the authors based on the data from the World Resource Institute, CAT (Climate Data Explorer database): http://cait.wri.org/historical/Country/

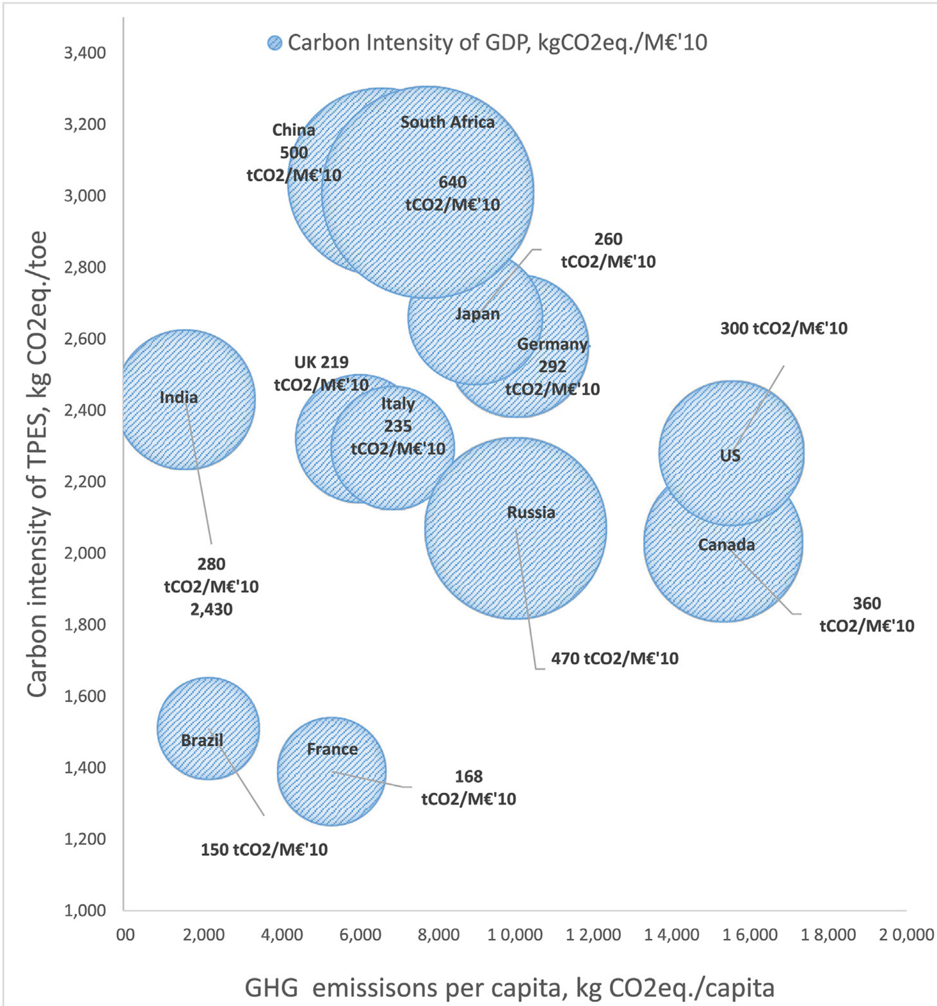

Fig. 11. (*continued*).

total GHG emissions has declined by 2% points due to decline of the share of G7 countries by 2% points (GHG emissions has decreased almost by 6 points in US during this period and have changed just insignificantly in other countries). Therefore, the input in total GHG emissions of the G7 and BRICS countries has changed dramatically during 17 years since 1990 as the share of BRICs countries increased by 10% points and the share of G7 has decreased by 10% points.

The GHG reduction policies and climate change mitigation efforts in the G7 and BRICS countries are the major drivers of changes in the global GHG emissions. The Copenhagen accord is a voluntary agreement signed in 2009 between 180 countries, making up over 80% of the global population and over 85% of the global emissions. This agreement is similar to the Kyoto concept, except that each country's acceptance and participation is not mandatory. Moreover, each country will commit to report their changes. The agreement is on a goodwill basis and assumes that each country will live up to their part in saving the climate by reducing the greenhouse gases. The GHG reduction targets were set for 2020, comparing with the levels in 1990.

In 2015, 196 Parties agreed in Paris to transform their development trajectories, aiming to limit global warming from 1.5 to 2 °C above the pre-industrial levels. The Paris Agreement requires all the Parties to make efforts to reduce the GHG emissions through the nationally determined contributions (NDCs). Table 5 summarizes G7 and BRICS countries' GHG reduction commitments for the G7 and BRICS countries.

As one can see from Table 5, BRICS countries' commitments for 2020 and 2030 are linked with the increase of GHG emissions above 1990, and G7 group countries committed themselves to reduce the GHG emissions below the 1990 level. Some countries have set targets for renewables as well (China, India), and some have targets expressed in carbon intensity reduction, like China and India, and some in total GHG amounts, like Brazil. Most of the countries have targets that are expressed in the GHG emission reduction to the base year, which is as well varying across the countries. In order to get a compatible picture, all the GHG reduction targets were recalculated as total GHG emission reductions in 2020 and 2030, comparing to the base year 1990.

3.3.1. China

China was responsible for 24% of the total GHG emissions in 2016 and 9.5% in 1990. As one can see from Table 6, in 2016 China had a GDP/capita, TPES/capita lower than the world average; however, GHG/capita, energy and carbon intensity of GDP are significantly higher than the world average in China due to the energy intensive industrial structure and low energy efficiency and high share of coal in the primary energy supply.

The carbon and energy intensiveness of China's GDP is linked to the chosen path of development (National Development and Reform Commission P.R. China, 2017). The increase of GHG emissions from fuel combustion sector in China is linked to the expanding energy and transport services due to its fast

Table 3
Ranking of G7 and BRICS countries based on GHG profiles, recent development trends of GHG profiles and climate policies in place.

Country	GDP/capita		GHG/capita		GDP/capita rating		TPES/GDP		GHG/TPES		RES/TPES		GHG target 2050	Long term GHG reduction strategy	Policies to promote RES	Policies to phase out coal	Net zero defo-restation	Total	Rank
	Current 2017	Trend 2012–2017	Current 2017	Trend 2012–2017	Current 2017	Trend 2012–2017	Current 2017	Trend 2012–2017	Current 2017	Trend 2012–2017	Current 2017	Trend 2012–2017							
UK	4	2	4	5	5	5	3	5	4	5	4	5	24	5	2	5	3	71	1
Italy	4	1	4	5	5	3	3	4	4	5	4	4	24	2	3	4	3	60	4
France	4	2	4	4	3	3	2	4	5	2	3	4	21	5	5	4	3	61	3
Germany	4	4	3	3	4	4	2	3	2	2	4	4	19	5	5	3	5	61	3
EU	4	3	4	4	4	4	2	4	4	5	4	4	22	3	4	3	4	64	2
Japan	5	2	2	3	4	4	2	4	2	3	2	4	17	3	3	1	3	50	5
US	5	4	1	3	2	3	1	3	3	4	3	3	15	1	2	1	3	43	7
Canada	5	4	1	2	1	2	1	2	3	2	2	3	13	3	1	4	2	41	8
Russia	3	3	2	5	1	3	1	3	3	2	1	2	11	1	3	1	3	37	9
South Africa	2	1	3	3	1	3	3	4	1	1	2	3	12	4	3	3	3	44	6
Brazil	2	1	5	3	3	1	5	3	5	1	5	3	25	2	4	3	3	52	4
India	1	5	5	1	3	5	5	1	3	2	3	3	20	2	4	2	5	52	4
China	2	5	3	2	2	5	3	2	1	4	2	5	13	4	3	1	5	51	5

Source: created by the authors based on (Climate Transparency, 2018) and data from the World Resource Institute, CAT (Climate Data Explorer database): http://cait.wri.org/historical/Country/

urbanization path (Viola and Basso, 2016). The world's largest GHG emitter, China is the largest consumer of coal and the largest solar technology manufacturer, and the choice it makes between the technology of the past versus the future will contribute significantly on the world's ability to limit warming to 1.5 °C. China has policies in place to reduce energy intensity and carbon intensity of GDP and if country will further foster use of renewables and energy efficiency improvements as country has sufficient financial resources and technical capabilities to do this, GHG emissions will start to decline instead of rising in China (Climate Transparency, 2018). The major climate change mitigation efforts since the Paris agreement: Renewable energy and nuclear power development; Cap on coal use; Promoting energy conservation to slow down the growth of energy demand (Carbon Brief, 2018; Clean Technica, 2018). China has set its GHG emission reduction targets in terms of carbon intensity of GDP (60%–65% below 2005 by 2030 and 40–45% below 2005 by 2020) in Table 5. These targets do not seem very ambitious (Climate Transparency, 2018), taking into account the fact that Chinese GHG emissions have increased more than 3 times since 1990; therefore, more strict policies to increase the energy efficiency and replace the coal generation by renewable energy sources are necessary.

3.3.2. Russia

The GHG emissions in Russia have decreased by more than 20% between 1990 and 2016. As one can see from Table 6, in 2016 Russia's GDP/capita, TPES/capita, GHG/capita and energy and carbon intensity of GDP are higher than the world average due to the energy intensive industrial structure and low energy efficiency in energy generation and consumption. It is necessary to stress that GHG/capita is very high in Russia (10.34 t CO_2eq./capita), comparing with the world average (4.46 t CO_2eq. in 2016), and this greatly differs from all the other BRICS countries, even China. Such high GHG/capita is linked to the carbon life style inefficiency, as living standards and economic development level in Russia are quite bellow the G7 countries' levels. The GHG emission reduction in Russia during 1990–2016 was achieved due to the economic decline, because this country does not have strict policies to increase the renewables and energy efficiency (The Ministry of Natural Resources of Russian Federation, 2017; Climate Transparency, 2018). In addition, Russia is the only big GHG emitter that has not yet ratified the Paris Agreement and may delay ratification until at least 2020. A first step should be the ratification of the Paris Agreement and setting out actual GHG emissions reductions target beyond the current policy scenario (Climate Transparency, 2018). Russian GHG emission reduction targets for 2030 is the reduction of GHG emissions by 25–30% below 1990 in 2030 and 5–25% below 1990 in 2020, including LULUCF (Table 5). Taking into account the fact that Russian GHG emissions have declined by more than 20% since 1990, the set target does not seem ambitious and requiring huge GHG emission reduction efforts.

3.3.3. India

Indian GHG emissions increased by 154.11% during 1990–2016. As one can see from Table 6, in 2016 India's GDP/capita, TPES/capita, GHG/capita were significantly below the world average. India has quite low energy intensity of GDP due to the developed low energy intensive service sector; however, the carbon intensity of energy balance is high as 71% of India's electricity comes from coal. Energy intensity has significantly reduced in India during recent years (2012–2017) by 12.79% points and in 2017 the target to reduce energy intensity by 20% was implemented. The successfully implemented Perform, Achieve and Trade (PAT) scheme aiming at energy efficiency improvements made a substantial contribution to the achievement of country's climate targets. India has set the

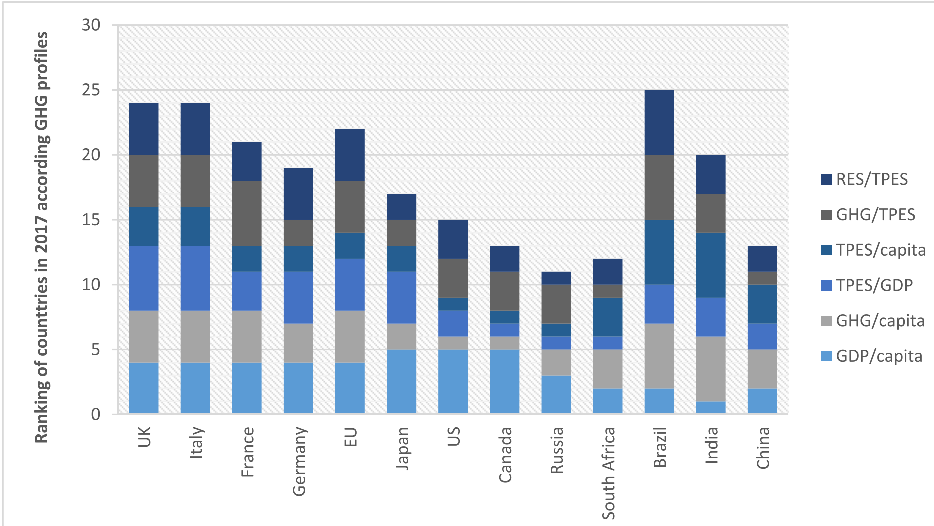

Fig. 12. The Ranking of countries in 2017 according GHG profiles.
Source: created by the authors based on (Climate Transparency, 2018) and data from the World Resource Institute, CAT (Climate Data Explorer database): http://cait.wri.org/historical/Country/

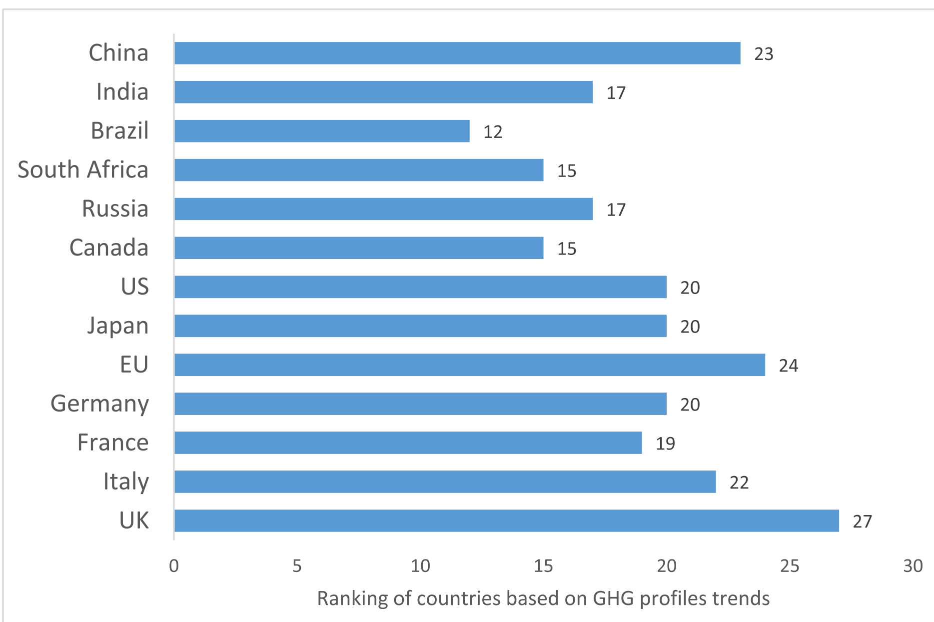

Fig. 13. The Ranking of countries based on recent developments of GHG profiles (2012–2017).
Source: created by the authors based on (Climate Transparency, 2018) and data from the World Resource Institute, CAT (Climate Data Explorer database): http://cait.wri.org/historical/Country/

target GHG emission intensity of GDP reduction by 33%–35% below 2005 in 2030 or the increase of GHG emissions by 501–518% above 1990 in 2030 and by 278–300% above 1990, excluding LULUCF (Table 5). Taking into account very low overall GHG emission profile of India and ambitious policies to promote energy efficiency and renewables (Government of India, 2015), it is possible to conclude that India can be a global climate leader in the near future (Climate Transparency, 2018).

3.3.4. Brazil

Brazilian GHG emissions, including LULUCF, declined by 35% between 1990 and 2014. First, the emissions, including LULUCF, are greater than emissions that are excluding it (see Table 4). Second, Brazil has successfully tackled its LULUCF's emissions between 1990 and 2014, but the emissions from the other sectors have increased in the same period. As one can see from Table 6, Brazil's GDP/capita, TPES/capita, and GHG/capita are lower, comparing with the world average. In addition, the energy intensity of GDP is quite low in the country due to the developed low energy intensive agriculture sector. Therefore, Brazil does not have the energy and carbon intensive economy as other BRICS countries. The country is broadly self-sufficient in energy. LULUCF, especially the deforestation, was the major driver of Brazilian GHG emissions (Ministry of Science Technology and Innovation of Brazil, 2015). Brazilian GHG emission reduction targets are to increase the GHG emissions, excluding LULUCF, by 73% above 1990 levels in 2030 and to increase

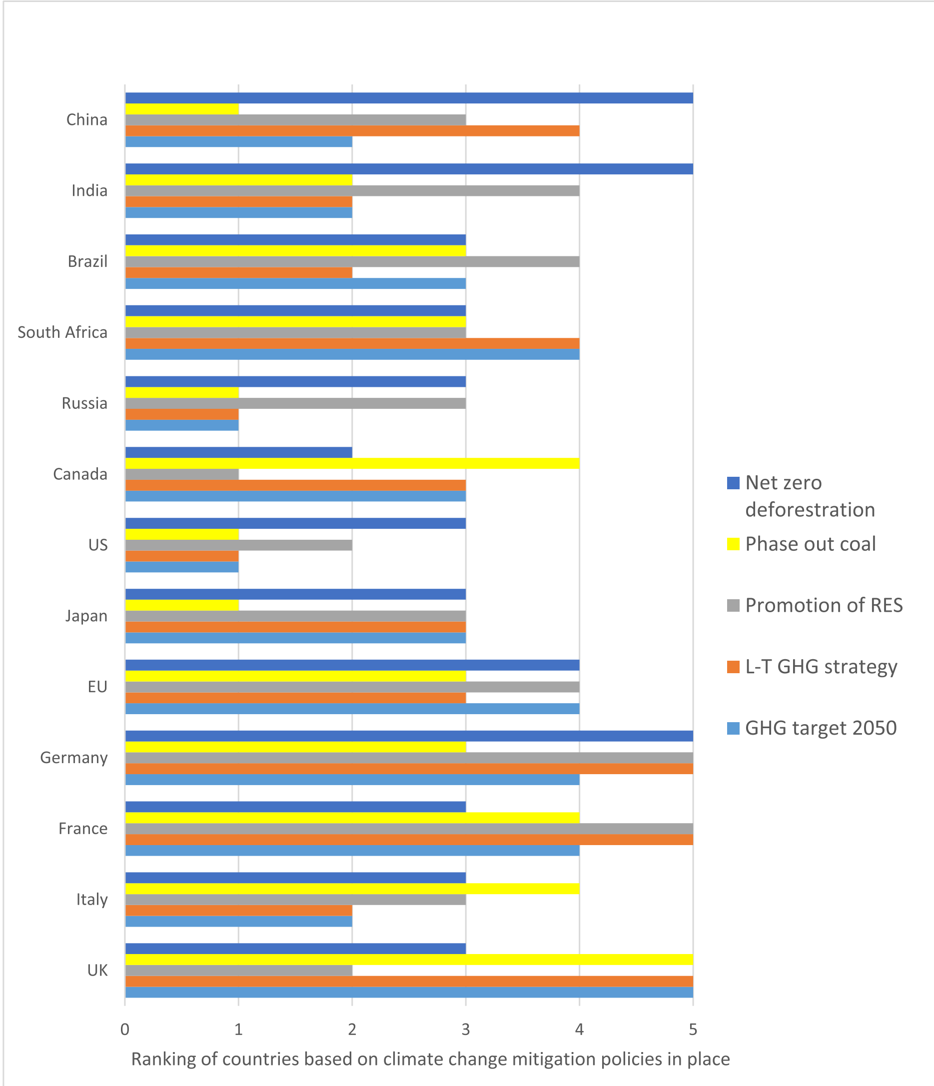

Fig. 14. The Ranking of countries based on climate change mitigation policies in place.
Source: created by the authors based on (Climate Transparency, 2018) and data from the World Resource Institute, CAT (Climate Data Explorer database): http://cait.wri.org/historical/Country/

the GHG emissions, excluding LULUCF, by 117–134% above 1990 in 2020. Based on the negative developments in GHG trends, it is obvious that the Brazilian government needs to strengthen climate change mitigation actions, especially in LULUCF and energy sectors (Climate Transparency, 2018).

3.3.5. South Africa

Between 1990 and 2016, South Africa's GHG emissions with and without LULUCF have increased by about 70%. As one can see from Table 6, South Africa's GDP/capita, TPES/capita were lower, comparing with the world average, but the country has as a quite high energy intensity of GDP and very higher carbon intensity of energy balance due to coal-fired electricity generation. Recently adopted South African Integrated Resource Plan includes a shift away from coal, increased adoption of renewables and gas, and an end to the expansion of nuclear power. South Africa's NDC target is equivalent to 19–82% increase from 1990 levels, excluding LULUCF. South Africa's NDC is consistent with its pledge under the Copenhagen Accord, which includes 19–73% increase in the emissions, excluding LULUCF, in 2020 and 19–82% increase in 2025 on 1990 levels, excluding LULUCF (Table 5). Taking into account recent GHG emission development trends (Department of Environmental Affairs, 2017; Climate Transparency, 2018), the government of South Africa decided to strengthen its climate change mitigation efforts and has developed a climate law in 2018 establishing the sectoral emission targets (SETs) for each greenhouse gas emitting sector in line with the national emission target for every five years.

3.3.6. EU member states

G7 countries are the most important players in decarbonization; however, their policies and GHG emission reduction efforts differ (European Commission, 2017b). G7 members: Germany, France, Italy, and the UK, have significantly reduced their GHG emissions from 1990 and are following the EU climate change mitigations policies. The GHG emissions in the European Union since 1990 (taken as the base year) was reduced by 24.4% in 2016, i.e., about 1383.40 million tonnes of CO_2 eq. Across the EU Member States in 2014–2016, the GHG were the highest in Germany (21% of the EU-28 total or 936 million tonnes of CO_2eq.), followed by the United Kingdom and France. The share of the EU's GHG emissions,

Table 4
Total GHG emissions in G7 and BRICS nations in 2014 ($MtCO_2e$).

	1990, including LULUCF	1990, excluding LULUCF	1990 % of world emissions, including LULUCF	1990 % of world emissions, excluding LULUCF	2014, including LULUCF	2014, excluding LULUCF	2014 % of world emissions, including LULUCF	2014 % of world emissions, excluding LULUCF
G7 nations								
Canada	641.34	560.04	1.89	1.84	867	745.11	1.77	1.63
France	468.91	492.73	1.38	1.62	334.28	413.11	0.68	0.90
Germany	1103.55	1154.11	3.25	3.79	816.64	854.01	1.67	1.87
Italy	486.76	491.02	1.43	1.61	368.2	403.11	0.75	0.88
Japan	1096.72	1171.04	3.23	3.85	1322.5	1314.59	2.70	2.87
The UK	725.58	737.73	2.14	2.42	493.9	506.11	1.01	1.11
The US	5550.04	5866.64	16.35	19.28	6319.02	6371.1	12.92	13.93
BRICS								
China	3218.45	3320.97	9.48	10.92	11600.63	11911.71	23.73	26.04
Russia	2776.78	2776.78	8.18	9.13	2030.14	2137.83	4.15	4.67
India	1212.02	1239.06	3.57	4.07	3202.31	3079.81	6.55	6.73
Brazil	1606.59	565.09	4.73	1.86	1357.18	1051.01	2.78	2.30
South Africa	309.29	307.21	0.91	1.01	527.22	524.89	1.08	1.15
World	33937.21	30423.75			48892.37	45740.7		
G7	10072.9	10473.31	29.68	34.42	10521.54	10607.14	21.52	23.19
BRICS	9123.13	8209.11	26.88	26.98	18717.48	18705.25	38.28	40.89
G7+BRICS	19196.03	18682.42	56.56	61.41	29239.02	29312.39	59.80	64.08

Source: created by the authors, based on the data from the World Resource Institute, CAT (Climate Data Explorer database): http://cait.wri.org/historical/Country/

Table 5
Sustainable energy development indicators linked to the climate in the G7 and BRICS countries, 1990 and 2016.

	FRA	DEU	ITA	UK	EU	CAN	JPN	US	BRA	CHN	IND	RUS	ZAF
1990													
EC1	28990	30510	30190	26480	24630	30900	28960	36230	10190	1480	1740	18310	9720
EC2	2.46	3.04	2.03	2.42	2.28	5.84	2.32	5.17	0.74	0.58	0.28	4.218	1.39
EC3	0.13	0.15	0.09	0.14	0.14	0.25	0.12	0.21	0.09	0.52	0.21	0.32	0.25
EN1	408.10	1064.20	439.10	608.00	44530.50	419.50	1042.00	4803.40	184.90	2077.40	530.70	2163.50	243.90
EN2	1.77	2.97	2.81	2.85	2.66	2.38	2.51	1.31	2.38	1.74	2.46	2.68	2.08
EN3	0.28	0.55	0.33	0.49	0.50	0.48	0.29	0.53	0.12	1.24	0.35	0.80	0.68
EN4	10.41	0.65	14.41	1.63	–	22.02	0.04	6.13	49.86	34.08	3.78	16.63	58.85
EN5	7.01	13.45	7.75	10.64	9.53	15.15	8.43	19.20	1.23	1.83	0.60	14.59	6.63
2014													
EC1	36770	42280	32900	37660	34130	42240	34900	50680	14920	12370	5270	22410	12200
EC2	2.21	2.68	1.92	1.90	2.10	5.52	2.32	4.80	1.12	1.37	0.43	3.19	1.38
EC3	0.10	0.09	0.07	0.07	0.09	0.19	0.10	0.14	0.1	0.7	0.12	0.22	0.22
EN1	348.00	819.10	356.10	463.20	3606.30	554.40	1184.80	5168.30	473.90	9031.50	2020.70	1487.10	434.80
EN2	1.39	2.60	2.33	2.41	2.19	1.99	2.70	2.30	1.57	3.06	2.44	2.05	2.99
EN3	0.17	0.30	0.23	0.23	0.27	0.37	0.27	0.32	0.15	0.54	0.30	0.46	0.66
EN4	13.13	7.29	9.80	2.84	16.10	22.58	0.01	16.05	41.81	17.10	16.59	36.54	8.91
EN5	5.28	10.14	5.86	7.20	7.11	15.60	9.32	16.19	2.30	6.62	1.56	10.34	8.03

Source: created by the authors, based on the data from the World Resource Institute, CAT (Climate Data Explorer database): http://cait.wri.org/historical/Country/

including LULUCF in total GHG emissions, has declined from 14.60% in 1990 to 7.41% in 2014. The total GHG emissions, excluding LULUCF, have declined from 17.24% in 1990 to 8.86% in 2014. The GHG emissions in Germany in 1990 accounted for 3.20% of the total GHG emissions, including LULUCF, and in 2014, their share halved to 1.67%. The GHG emissions, including LULUCF, in France, Italy, and the UK have reduced significantly during the period of 1990–2014, and their share in total GHG emissions with LULUCF have declined from 1.38% to 0.68% in France, from 1.43% to 0.75% in Italy, and from 2.14% to 1.10% in the UK during the investigated period (European Commission, 2017b).

As one can see from Table 6, Germany, France, Italy and UK have a similar GHG profile (high GDP/capita, TPES/capita, and GHG/capita). Though EU's GHG emissions from the electricity generation sector have been decreasing at the fastest rate, comparing with all other sectors during the last two decades, there is some slowdown in the development of renewables within the EU (European Commission, 2017b). In Table 5, the GHG reduction targets for Germany, France, Italy, and the UK (consistent with the EU target) are provided, i.e., to reduce the GHG 40% below 1990 in 2030 and 20% below 1990 in 2020. The target for 2050 is as well-being set by the EU to reduce the GHG emissions by 80–95% below 1990 (economy wide GHG emissions). The EU is a world leader in the climate change mitigation efforts and has implemented various GHG emission reduction policies; however, additional policies are necessary to meet the EU targets for 2030 and 2050.

3.3.7. *Canada*

The share of Canadian GHG emissions, including LULUCF in total GHG emissions, has insignificantly declined from 1.89% in 1990 to 1.77% in 2016. Canada has very high GDP/capita, TPES/capita, and GHG/capita (Table 6). Canada has adopted a Framework on Clean Growth and Climate in 2016. This document is the main strategy for the GHG emission reduction in Canada. It includes economy-wide GHG mitigation measures such as carbon pricing, phasing schedule of coal plants (The Government of Canada, 2017). Canada's Paris Agreement (NDC) target is to increase economy-wide GHG emissions by 4% above 1990, excluding LULCF, in 2030 (decrease by

Table 6
Summary of the pledges and targets in the G7 and BRICS countries.

	RES targets	2030 unconditional target	Copenhagen accord 2020	Long-term goals by 2050
G7				
Canada		30% below 2005 (4% above 1990), excluding LULCF	17% below 2055 (17% above 1990), excluding LULCF	80% net emissions below 2005
France		40% below 1990	20% below 1990	80–95% below 1990
Germany		40% below 1990	20% below 1990	80–95% below 1990
Italy		40% below 1990	20% below 1990	80–95% below 1990
Japan		26% below 2013 (18% below 1990), including LULCF	3.8% below 2005 (9% above 1990), excluding LULCF	80% below 1990
The UK		40% below 1990	20% below 1990	80–95% below 1990
The US		26–28% below 2005 by 2025 (9–17% below 1990) by 2025, excluding LULUCF	17% below 2005 (0–15% below 1990), excluding LULUCF	68–76% below 1990 (76% below 1990), including LULUCF
BRICS				
China	Non-fossil share 20% in 2030 Non-fossil share 15% in 2020	Reduction of carbon intensity by 60% –65% below 2005 (300–330% above 1990)	Reduction of carbon intensity by 40% –45% below 2005 (360–396% above 1990)	–
Russia		25–30% below 1990, including LULUCF	15–25% below 1990, including LULUCF	–
India	Non-fossil share 40% in 2030	Reduction of GHG emission intensity of GDP by 33%–35% below 2005 (501 –518% above 1990), excluding LULUCF	Reduction of GHG emission intensity of GDP by 20%–25% below 2005 (278 –300% above 1990, excluding LULUCF)	–
Brazil		1.2 $GtCO_2$ eq. in 2030 (55% above 1990 levels, excluding LULUCF) (excluding LULUCF	117–134% above 1990, excluding LULUCF	–
South Africa		GHG emissions with LULUCF between 398 and 614 MtCO2 over 2025–2030 (20–82% above 1990), excluding LULUCF	20–73% above 1990, excluding LULUCF	34% below to 28% above 1990, excluding LULUCF

Source: created by the authors, based on the data from UNFCCC, INDCs as communicated by the Parties available at: http://www4.unfccc.int/submissions/INDC/Submission%20Pages/submissions.aspx

30% below 2005 levels by 2030) and increase by 17% above 1990, excluding LULUCF, in 2020 (decrease by 17% below 2005 levels by 2030). Based on the current GHG trends and implemented policies, Canada is likely to miss its Paris agreement, and additional policies and measures are necessary, taking into account the GHG profile of this country and its negative trends.

3.3.8. Japan

The share of Japan GHG emission, including LULUCF in the total GHG emissions, has decreased from 3.23% in 1990 to 2.7% in 2016. Japan has high GDP/capita, TPES/capita, and GHG/capita (Table 6). Japan has very low share of renewables in energy supply the carbon intensity of GDP in Japan is higher than the world average. The share of renewable energy in total electricity generation has increased considerably, i.e., from 8.8% in 2010 (pre-Fukushima) to 15.0% in 2016, partly due to the generous feed-in tariff scheme that was introduced in 2012 (The Government of Japan, 2017). Japan's GHG emission reduction commitments are as follows: the reduction of GHG emissions by 26% below 1990, including LULUCF, in 2030 and an increase by 9% above 1990, excluding LULUCF, in 2020. It is difficult to predict Japan's future GHG due to the uncertainty around the future role of nuclear, coal, and renewables. Taking into account Japans' GHG emission profile and the development trends, the government should introduce stricter GHG mitigation policies and actions.

3.3.9. The United States

The US total GHG emissions, including LULUCF, have increased by 15% and by 9%, excluding LULUCF, during 1990–2016 period. The US has a high GDP/capita, TPES/capita, and GHG/capita (Table 6). The country performs especially low in the category of GHG and energy use per capita. Trump Administration's intent to withdraw from the Paris Agreement creates many concerns in other G7 countries and all over the world. The US GHG reduction target that was set by the Obama Administration is the reduction of GHG emissions by 0–15% below 1990 by 2020, excluding LULUCF, and the reduction of GHG emissions by 9–17% below 1990 by 2025, excluding LULUCF. The long-term target is the reduction of GHG emissions by 76% below 1990, including LULUCF, in 2050. In order to meet the Paris agreement target, the US would have to implement climate change mitigation policies that were foreseen by Obama Administration such as Climate Action Plan, Clean Power Plan, etc. (The US Department of State, 2016); however, the new US administration failed to submit its third Biennial Report to the UNFCCC, showing that the climate change mitigation is no longer a priority for the US government.

3.4. Ranking of GHG reduction efforts in BRICS and G7

The ranking of G7 and BRICS countries based on climate change mitigation policies in place was performed. The main climate change mitigation policies having impact on GHG emission profiles of G7 and BRICs countries are: setting GHG emission target for 2050 and beyond and preparing long-term energy efficiency improvement and GHG emission reduction strategy to achieve this goal; policies to promote renewables especially in power and heat production sector; policies to phase-out coal and policies to reduce deforestation.

The scoring of policies is based on the assessment of climate change mitigation efforts set up until 2017. The following categories are established on a five-point scale: 5–1.5 °C compatible policy actions are envisaged; 4 –significant actions and a long-term vision are envisaged; 3 –some actions are envisaged; 2 – limited actions are envisaged; and 1 – extremely limited actions are envisaged.

In terms of climate change mitigation policies, Germany, France, UK, EU and South Africa are the highest ranking countries. The US and Russia are ranked as the worst performing countries, with Japan and Canada ranked slightly above. Brazil, India and China are

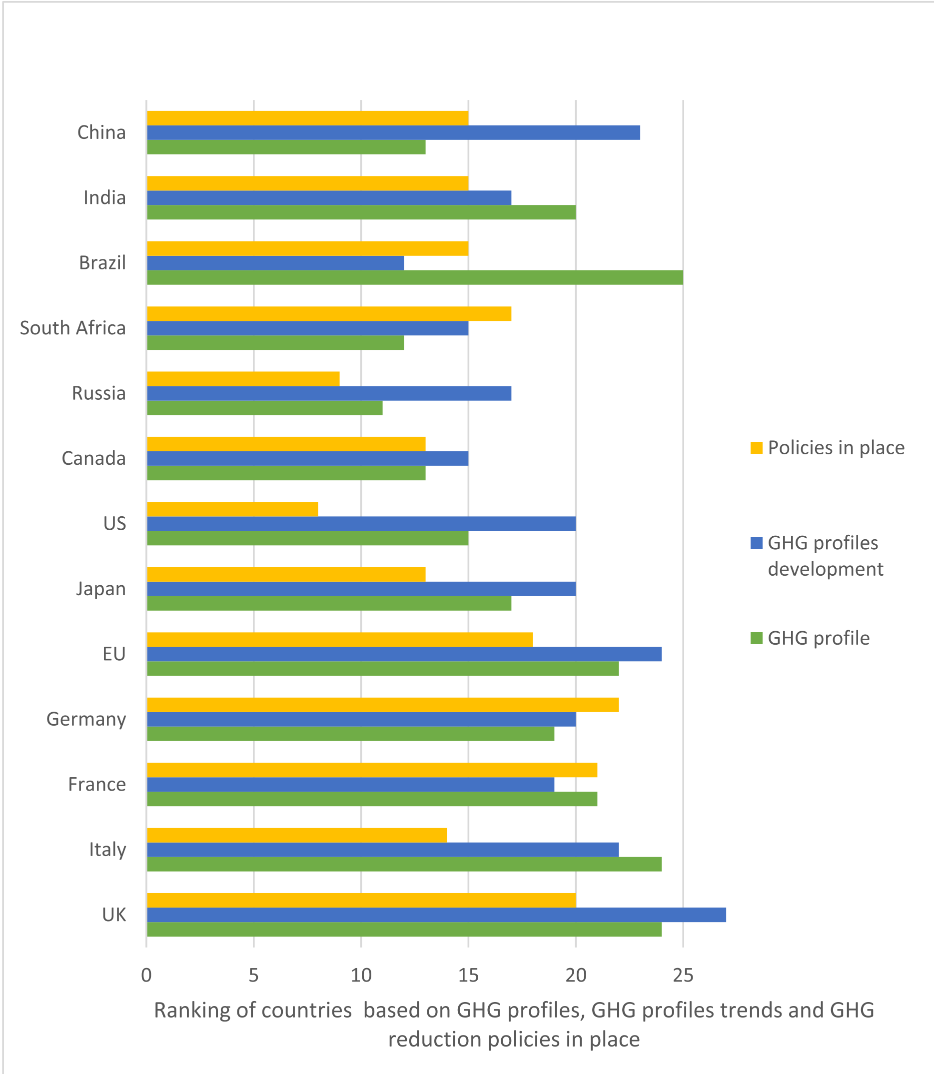

Fig. 15. Ranking of countries based on GHG profiles, GHG profiles trends and GHG reduction policies in place.
Source: created by the authors based on (Climate Transparency, 2018) and data from the World Resource Institute, CAT (Climate Data Explorer database): http://cait.wri.org/historical/Country/

in the middle of the ranking (Fig. 15).

Therefore, the leaders of climate change mitigation taking into account current GHG profile, development trends and climate change mitigation policies in place are EU member states, Brazil and India. Lagging behind are Russia, the US and Canada (Table 3; Fig. 15).

Therefore, the best performing countries in developing ambitious climate change mitigation policies are EU member states and South Africa, whereas the worst performing ones are: Russia, US and Canada.

4. Discussion

4.1. GHG emission profiles and drivers

Comparing the results of GHG emission profiles and their drivers' analysis with the results of other studies (Zhou et al., 2012), similar results have been obtained, indicating the better carbon emission performance and integrated energy-carbon performance of the G7 countries. The trend of GHG emission/capita convergence between G7 and BRICS countries is as well in line with the results of other studies (Li and Lin, 2013).

The analysis of GHG emission driving force development in BRICS countries showed the positive impact of GDP/capita growth on GHG/capita emissions growth, and this is in line with other study results (Al-mulali, 2012; Robalino-López et al., 2015; Liu et al., 2019). The decreased in energy intensity was the main driver of GHG/capita reduction in the G7 and BRICS countries, though in the BRICS countries, the affluence effect dominated there and exceeded the contribution of the energy intensity. This in line with the results of other studies on the decomposition of GHG emissions that were performed for some G7 and BRICS countries (Al-mulali, 2012; Robalino-López et al., 2015; Liobikiene and Butkus, 2018). The studies (Wu et al., 2005; Xu et al., 2016; Shen et al., 2018) also have presented the similar findings in terms of the major drivers of GHG emissions in fuel combustion sector.

As previous studies do not provide a clear linking of GHG emission trends to the implemented climate change mitigation policies in the G7 and BRICS countries, in the following section, the attempt to overcome this gap is made by performing a qualitative assessment of climate change mitigation policies and ability to comply with Paris agreement targets by the major climate change players.

Most of the BRICS countries are experiencing GHG emission growth due to fast economic growth and weak climate change mitigation policies in the energy sector. The implemented climate change mitigation policies to promote renewables and energy efficiency have not contributed to the changing of GHG emission trends and their drivers. The findings of comparative assessment of climate change mitigation policies in BRICS and G7 are in line with other studies that have a more narrow scope. The revealed difference in energy-decoupling rates in the G7 and BRICs by Tu et al. (2016) was as well noticed during the analysis of the main drivers of GHG emissions, including policies.

4.2. Climate change mitigation policies

The results of comparative climate change policy assessment and ranking of countries are as well in line with Zhou et al. (2012) who found that G7 countries show better carbon emission performance in the energy sector due to the implemented rigorous climate change mitigation policies. The policies to promote energy efficiency and renewable energy consumption have significant impact on the GHG emission reduction in the EU member states and China (Al-mulali, 2012; Robalino-López et al., 2015; Liobikiene and Butkus, 2018).

In BRICs group, only China's climate change mitigation policies have contributed to changing the GHG emissions trend since 2014. China is implementing renewable energy and nuclear energy; however, the high-energy intensity of GDP and high carbon intensity of energy supply and high GDP growth require more ambitious policies in order to increase the energy efficiency in supply and demand side and replace the coal generation by renewable energy sources. Most studies (Liu et al., 2014; Hao et al., 2015; Yi et al., 2016) showed that the economic and population growth are the most important drivers behind the GHG emission change in China, and this country will be able to implement GHG emissions reduction target by 2020 due to the increased share of renewables and nuclear (Koo et al., 2014).

India's GHG emissions more than doubled between 1990 and 2016, and that trend is expected to continue; however, the energy intensity of GDP and the share of renewables have increased during this period significantly. Therefore, taking into account very low overall GHG emission profile of India and ambitious policies to promote renewables and energy efficiency, it is possible to conclude that India can be a global climate leader and an example for the other BRICS countries. This is in line with the study by Paul and Bhattacharya (2004), presenting the results of decomposition of GHG emissions in India.

Brazil has low energy and carbon intensive economy, and the deforestation was the major driver of Brazilian GHG emissions. Due to strict climate change policies in this area, Brazils' GHG emission have declined during 1990–2016, but the government has cut back on implementing policies to reduce the emissions from forests, and this will have an impact on the GHG emission growth. Chen et al. (2013) found that cutting of GHG emissions would have some negative impacts on the Brazilian economy due to the reduction of deforestation rates.

South Africa has experienced GHG emission growth during 1990–2016. Taking into account quite high overall GHG emission profile and weak climate change mitigation policies in the energy sector, it is necessary to strengthen climate change mitigation efforts in order to implement the Paris agreement. This is in line with the results of analysis performed by Ireland and Burton (2018) and the Department of Energy (2018).

Russian's GHG emission decline during 1990–2016 has been achieved due to the economic decline, because this country has few small-scale policies to increase the renewables and energy efficiency. Taking into account very high-energy intensity of GDP and high carbon intensity of energy supply (due to high share of fossil fuels), the GHG emissions will increase in the case of economic growth if the country does not take serious GHG reduction efforts in the energy sector.

In G7 group, the EU Member States: Germany, France, Italy, and the UK, have significantly reduced their GHG emissions from 1990 and are following the EU climate change mitigations policies, though the negative trend of renewables penetration decrease can be noticed in the EU Member States. Study by Liobikiene and Butkus (2018) proved the major impact of renewable targets and policies in place on GHG emission reduction in the EU.

However, in other G7 members (Canada, Japan, and the US), quite alarming trends can be noticed. The Canadian GHG emissions have increased during 1990–2005 due to the lack of ambitious climate change mitigation efforts. Taking into account the low performance in the GHG profile and recent trends in the GHG emission and their drivers' development, one can notice that country needs to implement additional GHG mitigation, especially linked with the phasing of coal plants. The same conclusions are provided by the Government of Canada (2016) based on the in-depth evaluation of climate change mitigation policies impacts.

The GHG emissions and their drivers showed a negative trend of increase in Japan and the US. Taking into account Japan's and the US low performance in terms of GHG emission profile and their recent development trends, one can notice that the current climate change mitigation policies in place were not able to reverse negative GHG emission development trends, and stricter climate change mitigation efforts in the energy sector are necessary.'

4.3. Policy implications

Due to the high greenhouse gas profiles, low GHG reduction commitments and insufficient climate change mitigation efforts in both groups there is danger of postponing implementation of Paris commitments and achieving the 1.5° target. The policies implemented in high ranked countries, like the Perform, Achieve and Trade (PAT) scheme in India or Integrated Resources Planning and Climate law establishing the sectoral emission targets (SETs) for each greenhouse gas emitting sector in South Africa or measures under Energy efficiency directive in EU can be applied in low ranked countries by providing the substantial contribution to the country's climate targets.

Though showing positive path towards decarbonisation, China, having in mind high GHG emission profile and development trends, needs to implement stricter policies to replace coal with renewables and increase energy efficiency in demand and supply side in order to comply with the GHG emission reduction commitments. A negative trend in the GHG reduction efforts can be observed in Russia and Brazil, and the governments of these countries need to strengthen mitigation actions in energy sectors and Brazil especially in LULUCF.

In G7 group's GHG emission reduction efforts, some alarming trends can be noticed, especially taking into account high GHG emission profiles due to high share of coal in the energy supply of Canada, Japan, and the US and the weakening of current climate change mitigation policies in the energy sector, especially in the US. The recent trends in the EU and its G7 group members as well indicates alarming trends in the decrease of penetration of renewables; even though the EU is the world leader in GHG emission reduction initiatives and policies to promote an increase in the energy efficiency and utilization of renewables.

The input in total GHG emissions of the G7 and BRICS countries has changed dramatically during 17 years since 1990 as the share of

BRICs countries increased by 10% points and the share of G7 has decreased by 10% points, therefore, BRICS countries need to implement additional GHG emission reduction efforts, especially in the energy sector, which is the main driver of the economic growth and GHG emissions by learning from the experience of developed economies.

The energy intensity is the main driver of GHG emissions per capita therefore the main attention should be paid to policies promoting energy efficiency improvements in BRICS countries. Carbon factor showing the penetration of renewables in energy mix turned out to be the least important factor for both of the groups considered. This implied that further mitigation actions in BRICS should be first oriented towards decrease in energy intensity following the increase of zero carbon fuels in energy mix and coal phase-out, whereas carbon factor changes require more investments, what is more problematic for developing nations.

5. Conclusions

The three hypotheses of the study were tested and validated through the comparative assessment of GHG emission profiles and their drivers in the G7 and BRICS countries.

The analysis of GHG profiles of two groups of countries revealed that the G7 group countries have high GDP/capita that is adjusted to the PPP, high TPES/capita, high GHG emissions/capita, low carbon intensity, and low energy and carbon intensity of GDP with some exemptions, like Canada and Japan that are having high carbonization index due to the low share of renewables in the final energy consumption.

BRICS countries have low GDP/capita, low TPES/capita, and low GHG/capita, indicating lower life standards; however, high energy and carbon intensity of GDP and a high carbonization index with some exemptions, like Brazil that is having a low carbonization index and low energy and carbon intensity of GDP as well as low GHG/capita. This is linked to the high share of renewables in the energy supply and low share of energy industries in the economy.

Comparing the results of GHG emission profiles and their drivers' analysis with the results of the other studies, the similar results were obtained by indicating the better carbon emission performance and integrated energy-carbon performance of G7 countries. The trend of GHG emission/capita convergence between G7 and BRICS countries is as well in line with the results of other studies. GHG/capita has decreased in G7 countries and increased in BRICS countries during 1990–2017.

Energy intensity, economic growth and carbon factor are the main drivers of GHG/capita. Energy intensity was the major driver of decrease in GHG/capita during 1990–2017 for both groups of countries, however, the economic growth exceeded the contribution of energy intensity in BRICS countries and this is in line with the results of other studies on the decomposition of GHG emissions that were performed for some G7 and BRICS countries.

As previous studies have not addressed a clear linkage of GHG emission trends to implemented climate change mitigation policies in the G7 and BRICS countries, the current study tries to fill this gap by providing qualitative assessment of climate change mitigation policies and the ability to comply with the Paris agreement targets by major climate change players.

All the analyzed countries in the G7 and BRICS groups have ratified Paris agreement, except Russia and US announced intention to withdraw from Paris Agreement. In BRICS countries' GHG emission reduction commitments for 2020 and 2030 are linked with the increase of GHG emissions above 1990, and G7 group countries committed themselves to reduce the GHG emissions below the 1990 level. Some countries have set targets for renewables as well (China, India), and some have targets that are expressed in carbon intensity reduction like China and India and some in total GHG amounts like Brazil. Most of the countries have targets that are expressed in the GHG emission reduction to the base year, which is as well varying across countries. In order to get a compatible picture, all the GHG reduction targets were recalculated as total GHG emission reductions in 2020 and 2030, comparing to the base year 1990.

The leaders of climate change mitigation arena between major climate players are: EU member states, Brazil and India and the lagging behind countries: Russia, US and Canada. The best performing countries in developing climate change mitigation policies are: EU member states, India and South Africa and the worst performing countries are: Russia, US and Canada. The best results in decarbonisation trends during 2012–2017 were demonstrated by EU member states and China and the lowest achievements were demonstrated by Brazil, South Africa and Canada.

The main input of this paper is the development of sustainable energy indicators framework for the comparative assessment of GHG emission profiles and their drivers in the G7 and BRICS countries. The applied comparative assessment approach is simple, transparent and can be easily replicated for in-depth analysis of GHG mitigation efforts of countries. The additional strength of comparative assessment approach that is applied in the study is ability to use of both quantitative (GHG profiles and their drivers' dynamics analysis) and qualitative data (climate change mitigation policy review) analysis. The limits of this approach are mainly linked to the subjectivity in addressing climate change policy impacts on the GHG emission reduction and assessment of countries' abilities to comply with Paris agreement targets. The future research is necessary in order to integrate some additional policy analysis tools for the decomposition of GHG emissions by sectors and the main drivers based on the Kaya identity. These more robust techniques would allow extending the scope of the study and generating additional findings and forecasts.

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References

Al-mulali, A., 2012. Factors affecting CO_2 emission in the Middle East: a panel data analysis. Energy 44, 564–569.

Azevedo, V.G., Sartori, S., Campos, L.M.S., 2018. CO2 emissions: a quantitative analysis among the BRICS nations. Renew. Sustain. Energy Rev. 81, 107–115.

Belke, A., Dobnik, F., Dreger, C., 2011. Energy consumption and economic growth: new insights into the cointegration relationship. Energy Econ. 33 (5), 782–789.

Bossel, H., 1999. Indicators for Sustainable Development: Theory, Method, Applications. A Report to the Balaton Group. International Institute for Sustainable Development (IISD), Winnipeg, Canada.

Carbon Brief, 2018. Q&A: How Will China's New Carbon Trading Scheme Work?" accessed. https://www.carbonbrief.org/qa-how-will-chinasnew-carbon-trading-scheme-work. (Accessed 20 January 2019).

de Castro Camioto, F., Moralles, H.F., Mariano, E.B., do Nascimento Rebelatto, D.A., 2016. Energy efficiency analysis of G7 and BRICS considering total-factor structure. J. Clean. Prod. 122, 67–77.

Chang, M.C., 2015a. Room for improvement in low carbon economies of G7 and BRICS countries based on the analysis of energy efficiency and environmental Kuznets curves. J. Clean. Prod. 99, 140–151.

Chang, M.C., 2015b. Room for improvement in low carbon economies of G7 and BRICS countries based on the analysis of energy efficiency and environmental Kuznets curves. J. Clean. Prod. 99, 140–151.

Chang, M.C., Hu, J.L., 2018. A Long-Term Meta-Frontier Analysis of Energy and Emission Efficiencies between G7 and BRICS. Energ Effic, pp. 1–15. https://doi.org/10.1007/s12053-018-9696-7.

Chang, M.C., Hu, J.L., Jan, F.G., 2016. Resource efficiency and productivity changes in the G7 and BRICS Nations. Pol. J. Environ. Stud. 27 (6), 1–12.

Chen, Y.H.H., Timilsina, G.R., Landis, F., 2013. Economic implications of reducing carbon emissions from energy use and industrial processes in Brazil. J. Environ. Manag. 130, 436–446.

Chen, J., Cheng, Sh, Nikic, V., Song, M., 2017. Quo Vadis? Major players in global coal

consumption and emissions reduction. Transform. Bus. Econ. 1 (43), 112–132.
Clean Technica, 2018. Chinese Electric Vehicle Subsidy Changes in 2018 accessed. https://cleantechnica.com/2018/01/06/chinese-electric-vehiclesubsidy-changes-2018-details/. (Accessed 20 January 2019).
Climate Action Tracker, 2018. Climate Action Tracker Warming Projections Global Update accessed. https://climateactiontracker.org/documents/507/CAT_2018-12-11_Briefing_WarmingProjectionsGlobalUpdate_Dec2018.pdf. (Accessed 20 January 2019).
Climate Transparency, 2018. Brown to Green Report 2018. The G20 Transition to a Low-Carbon Economy accessed. https://www.climate-transparency.org/wp-content/uploads/2019/01/2018-BROWN-TO-GREEN-REPORT-FINAL.pdf. (Accessed 20 January 2019).
Department of Environmental Affairs, 2017. *South Africa's 2nd Biennial Update Report*.
Ecologic Institute, 2011. Linking Sustainability Indicators with Policy Making: Results and Conclusions of IN-STREAM accessed. http://go.nature.com/2tsnmWg. (Accessed 12 June 2018).
European Commission, 2017a. Monitoring Progress towards the Energy Union Objectives — Key Indicators. *Second Report on the State of the Energy Union*, Commission Staff Working Document, 1.2. 2017 SWD, Brussels, 2017) 32 final.
European Commission, 2017b. *7th National Communication & 3rd Biennial Report from the European Union under the UN Framework Convention on Climate Change (UNFCCC)* (Required under the UNFCCC and the Kyoto Protocol).
European Commission, 2018. Energy — Database — Indicators for Monitoring Progress towards Energy Union Objectives accessed. https://ec.europa.eu/energy/en/atico_countrysheets/scoreboard. (Accessed 25 April 2018).
Eurostat, 2015. Energy. Transport and Environment Indicators, Eurostat.
Eurostat, 2018. Sustainable Development Indicators: Theme 6: Climate Change and Energy accessed. http://ec.europa.eu/eurostat/web/sdi/indicators/climate-change-and-energy. (Accessed 12 June 2018).
Finland Future Research Centre, 2007. Development and Comparison of Sustainability Indicators (DECOIN) Project Presentation Leaflet accessed. http://go.nature.com/2tnym6F. (Accessed 25 June 2018).
Ghouli, G.Y., Mostefa, B., Abbes, S.M., Seghir, G.M., 2015. Factors affecting CO_2 emissions in the BRICS countries: a panel data analysis. Procedia Econ. Finance 26, 114–125.
Gil-Alana, L., Cunado, J., Gupta, R., 2016. Persistence, mean-reversion and non-linearities in CO_2 emissions: evidence from the BRICS and G7 countries. Environ. Resour. Econ. 25, 1–15.
Government of Canada, 2016. Canadian Framework on Clean Growth and Climate Change: Canada's Plan to Address Climate Change and Grow the Economy accessed. https://www.canada.ca/content/dam/themes/environment/documents/weather1/20170125-en.pdf. (Accessed 20 June 2019).
Government of India, 2015. First Biennial Update Report to the United Nations Framework Convention on Climate Change. Ministry of Environment, Forest and Climate Change, Government of India.
Hák, T., Janoušková, S., Moldan, B., 2016. Sustainable development goals: a need for relevant indicators. Ecol. Indicat. 60, 565–573.
Hao, Han, Geng, Yong, Li, Weiqi, Guo, B.H., 2015. Energy consumption and GHG emissions from China's freight transport sector: Scenarios through 2050, 2015. Energy Policy 85, 94–101.
Hardi, P., Barg, T., 1997. Measuring Sustainable Development: Review of Current Practice. Occasional Paper No. 17. Industry Canada.
Hirschberg, S., Bauer, C., Burgherr, P., Dones, R., Schenler, W., Bachmann, T., Carrera, D.G., 2007. Environmental, Economic and Social Criteria and Indicators for Sustainability Assessment of Energy Technologies. *New Energy Externalities Developments for Sustainability (NEEDS)*. Project Cofounded by the European Commission within the Sixth Framework Programme (2002–2006). Paul Scherrer Institut, Villigen PSI (Switzerland), p. 502687.
IAEA, 2005. Energy Indicators for Sustainable Development: Guidelines and Methodologies. International Atomic Energy Agency, United Nations Department of Economic and Social Affairs, International Energy Agency, Eurostat and European Environment Agency accessed. http://www.unosd.org/content/documents/1237Pub1222_web%20EISD.pdf. (Accessed 12 June 2018).
Iftikhar, Y., He, W., Wang, Z., 2016. Energy and CO_2 emissions efficiency of major economies: a non-parametric analysis. J. Clean. Prod. 139, 779–787.
IPCC, 2007. Climate change 2007: synthesis report. In: Core Writing Team, Pachauri, R.K., Reisinger, A. (Eds.), Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland, p. 104.
Ireland, G., Burton, J., 2018. An Assessment of New Coal Plants in South Africa's Electricity Future: the Cost, Emissions, and Supply Security Implications of the Coal IPP Programme". Energy Research Centre, University of Cape Town, Cape Town accessed. https://cer.org.za/wp-content/uploads/2018/05/ERC-Coal-IPP-Study-Report-Finalv2-290518.pdf. (Accessed 20 January 2019).
Kemmler, A., Spreng, D., 2007. Energy indicators for tracking sustainability in developing countries. Energy Policy 35 (4), 2466–2480.
Koo, C., Kim, H., Hong, T., 2014. Framework for the analysis of the low-carbon scenario 2020 to achieve the national carbon emissions reduction target: focused on educational facilities. Energy Policy 73, 356–367.
Li, X., Lin, B., 2013. Global convergence in per capita CO_2 emissions. Renew. Sustain. Energy Rev. 24, 357–363.
Lin, B., Ankrah, I., Manu, S., 2017. Brazilian energy efficiency and energy substitution: a road to cleaner national energy. J. Clean. Prod. 162, 1275–1284.
Liobikiene, G., Butkus, M., 2018. The challenges and opportunities of climate change policy under different stages of economic development. Sci. Total Environ. 642, 999–1007.
Liu, L.W., Zong, H.J., Zhao, E.D., Chen, C.X., Wang, J.Z., 2014. Can China realize its carbon emission reduction goal in 2020: from the perspective of thermal power development. Appl. Energy 124, 199–212.
Liu, C., Jiang, Y., Xie, R., 2019. Does income inequality facilitate carbon emission reduction in the US? J. Clean. Prod. 217, 380–387.
Ministry of Natural Resources of Russian Federation, 2017. Third Benial Report under the United Nations Framework Convention on Climate Change of Russian Federation (In Russian).
Ministry of Science Technology and Innovation of Brazil, 2016. Executive Summary — Third National Communication of Brazil to the UNFCCC. Ministry of Science Technology and Innovation, Brasilia, Brazil.
Mostafa, G., Mahmood, M., 2015. The rise of the BRICS and their challenge to the G7. Int. J. Emerg. Mark. 10, 156–170.
National Development and Reform Commission P.R. China, 2017. China's Policies and Actions for Addressing Climate Change.
Neves, A.R., Leal, V., 2010. Energy sustainability indicators for local energy planning: review of current practices and derivation of a new framework. Renew. Sustain. Energy Rev. 14, 2723–2735.
Niu, S., Ding, Y., Niu, Y., Li, Y., Luo, G., 2011. Economic growth, energy conservation and emissions reduction: a comparative analysis based on panel data for 8 Asian-Pacific countries. Energy Policy 39 (4), 2121–2131.
Onat, N., Bayer, H., 2010. The sustainability indicators of power production systems. Renew. Sustain. Energy Rev. 14, 3108–3115.
Pao, H.T., Tsai, C.M., 2010. CO_2 emissions, energy consumption and economic growth in BRIC countries. Energy Policy 38, 7850–7860.
Pao, H.T., Tsai, C.M., 2011. Multivariate granger causality between CO_2 emissions, energy consumption, FDI (foreign direct investment) and GDP (gross domestic product): evidence from a panel of BRIC (Brazil, Russian Federation, India, and China) countries. Energy 36, 685–693.
Paul, S., Bhattacharya, R., 2004. CO2 emission from energy use in India: a decomposition analysis. Energy Policy 32 (5), 585–593.
Robalino-López, Á., Mena-Nieto, A., García-Ramos, E., Golpe, A.A., 2015. Studying the relationship between economic growth, CO_2 emissions, and the environmental Kuznets curve in Venezuela (1980–2025). Renew. Sustain. Energy Rev. 41, 602–614.
Santana, N.B., Aparecida do Nascimento Rebelatto, D., Périco, A.E., Mariano, E.B., 2014. Sustainable development in the BRICS countries: an efficiency analysis by data envelopment. Int. J. Sust. Devt. World 21, 259–272.
Santana, N.B., Mariano, E.B., Camioto, F.D.C., Rebelatto, D.A.D.N., 2015. National innovative capacity as determinant in sustainable development: a comparison between the BRICS and G7 countries. Int. J. Sust. Devt. World 9, 384–405.
Scheller, A., 1999. Researchers' Use of Indicators. CEPE Working Paper 1. Zürich, Switzerland.
Shahbaz, M., Solarin, S.A., Sbia, R., Bibi, S., 2015. Does energy intensity contribute to CO2 emissions? A trivariate analysis in selected African countries. Ecol. Indicat. 50, 215–224.
Shen, L., Wu, Y., Shuai, C., Lu, W., Chau, K.W., Chen, X., 2018. Analysis on the evolution of low carbon city from process characteristic perspective. J. Clean. Prod. 187, 348–360.
The Government of Japan, 2017. Japans Third Biennial Report under the United Nations Framework Convention on Climate Change.
The US Department of State, 2016. 2016 Second Biennial Report of the United States of America under the United Nations Framework Convention on Climate Change.
Tsai, W.T., 2010. Energy sustainability from analysis of sustainable development indicators: a case study in Taiwan. Renew. Sustain. Energy Rev. 14, 2131–2138.
Tu, C.J., Chang, M.C., Chen, C.P., 2016. Progressive time-weighted dynamic energy efficiency, energy decoupling rate, and decarbonization: an empirical study on G7 and BRICS. Sustainability 8, 928.
Tugcu, C.T., Tiwari, A.K., 2016. Does renewable and/or non-renewable energy consumption matter for total factor productivity (TFP) growth? Evidence from the BRICS. Renew. Sustain. Energy Rev. 65, 610–616.
United Nations, 2012. Indicators for Monitoring the Millennium Development Goals accessed. http://go.nature.com/2uogXbZ. (Accessed 12 June 2018).
Viola, E., Basso, L., 2016. Wandering decarbonization: the BRIC countries as conservative climate powers. Rev. Bras. Política Int. 59 (1), e001.
Wang, C., Chen, J., Zou, J., 2005. Decomposition of energy-related CO2 emission in China: 1957–2000. Energy 30 (1), 73–83.
Wu, L., Kaneko, S., Matsuoka, S., 2005. Driving forces behind the stagnancy of China's energy-related CO2 emissions from 1996 to 1999: the relative importance of structural change, intensity change and scale change. Energy Policy 33 (3), 319–335.
Xu, L., Chen, N.C., Chen, Z.Q., 2017. Will China make a difference in its carbon intensity reduction targets by 2020 and 2030. Appl. Energy 203, 874–882.
Yi, B.W., Xu, J.H., Fan, Y., 2016. Determining factors and diverse scenarios of CO2 emissions intensity reduction to achieve the 40–45% target by 2020 in China—A historical and prospective analysis for the period 2005–2020. J. Clean. Prod. 122, 87–101.
Zhou, P., Ang, B.W., Wang, H., 2012. Energy and CO_2 emission performance in electricity generation: a non-radial directional distance function approach. Eur. J. Oper. Res. 221, 625–635.