J Syst Sci Syst Eng
DOI: 10.1007/s11518-014-5250-0
ISSN: 1004-3756 (Paper) 1861-9576 (Online)
CN11-2983/N

DESIGN AND ANALYSIS OF THE GREEN CLIMATE FUND*

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Abstract

The Green Climate Fund (GCF) has been one of the core issues of the world climate summits under the United Nations Framework Convention on Climate Change (UNFCCC) in recent years. However, the GCF has not progressed smoothly, and currently there are no satisfactory schemes for raising and distributing the fund. This paper first discusses how to finance the GCF among Annex II countries. It introduces the 'preference score compromises' (PSC) approach which is based on environmental responsibility and economic capacity, with historical emissions as an indicator for environmental responsibility and GDP as indicator for economic capacity. The results show that the United States and the European Union are the two largest contributors to the GCF, sponsoring more than 80% of the funds. Second, we discuss how to allocate the funds among non-Annex II parties. The 'adaptation needs' (AN) approach, which takes account of economic strength and climate damages, is proposed to achieve the adaptation purpose of the GCF, and the results reveal that African countries with high levels of climate vulnerability could get most funds, with a share of almost 30%. Regarding the mitigation purpose of the GCF, this research introduces two approaches: the 'carbon reduction contribution' (CC) approach and the 'incremental cost' (IC) approach. Both approaches could achieve significant reductions in carbon emissions in non-Annex II parties, whereas the latter may provide limited adaptation finance but result in more mitigation effects. This paper also develops a method to combine abatement efficiency and adaptation fairness of the GCF, and we find that with an equal split between the AN and CC (or AN and IC) approaches, the amount of USD 100 billion could finance an emissions reduction of 1613 $MtCO_2$ (2477 $MtCO_2$), while allocating USD 16 (or USD 9) per capita for adaptation in non-Annex II parties. The schemes proposed may be useful for promoting the development of the GCF in the future.

Keywords: Climate change, green climate fund, preference score compromises, carbon reduction contribution, mitigation and adaptation

*Supports from the National Natural Science Foundation of China under Grant No.71210005 and No. 71273253 are greatly acknowledged.

1. Introduction

Climate change has become one of the most important challenges of the 21 century. To address climate change and help developing countries enhance their resilience to climate change, an agreement to establish the Green Climate Fund (GCF) was achieved at the 2009 Copenhagen Summit of the United Nations Framework Convention on Climate Change (UNFCCC). As the sponsors, the developed countries are required to provide adequate, predictable and sustainable financial support for projects, programmes, policies and other activities in developing countries related to mitigation and adaptation (UNFCCC 2010).The GCF proposal was confirmed at the 2010 Cancun Summit, and rapidly became one of the core issues at the 2011 Durban Summit and the 2012 Doha Summit. The Copenhagen Accord and the Cancun Agreement stipulated that developed countries should provide USD 30 billion of fast-start funding between 2010 and 2012, and they set a goal of mobilizing USD100 billion per year by 2020 to address the needs of developing countries (UNFCCC, 2011).

However, the established period for the initial fast-start funding has expired, with the GCF having not progressed smoothly. At the 2012 Doha Summit, many developing countries criticized the rich, industrialized countries for failing to deliver on their promises, while the developed countries argued that they had fulfilled their fast-start financing commitment (Cui et al. 2014). The divergence of the GCF between the developed and developing countries erupted again at the 2013 Warsaw Summit. Although the COP 19 has specified that initial replenishment of the GCF should be achieved by end 2014, the detailed operational technical documents such as the burden-sharing of the GCF finance have not been mentioned (UNFCCC 2013). Thus, there is a great need of designing appropriate fund-raising and disbursement schemes to promote the development of the GCF.

The GCF was established for two main purposes: climate mitigation and climate adaptation. On the one hand, the climate vulnerabilities are not evenly distributed, and there is greater vulnerability in developing countries which have less historical carbon emissions, especially for the Least Developed Countries (LDCs) and African States with high poverty indices. Thus, it is necessary to provide financial support and technology transfers to help these developing countries strengthen their resilience to climate change. On the other hand, the developed countries agreed to provide the GCF funds in order to encourage the developing countries to reduce their emissions in an effort to combat climate change. Moreover, since the environment benefits from mitigation efforts in developing countries can be shared by developed countries, this will also muster the enthusiasm of the developed countries to finance the GCF. The GCF will strive to maximize the impact of its funding for adaptation and mitigation, and seek a balance between the two in the future (UNFCCC 2011).

One of the achievements of the UNFCCC negotiations is that the GCF has attracted wide spread attention since it was proposed. However, it appears that the scientific research on the

GCF is still at the initial stage. First, some scholars adopt a qualitative perspective in discussing the GCF. For instance, according to Van Kerkhoff et al. (2011), while climate mitigation is dominated by national scale policy and comprises a vast array of activities that are mostly local in scale, as the experience from the Clean Development Mechanism (CDM) shows, national implementing entities (NIEs) can be established for each developing country to manage the local use and supervision of the GCF. Donner et al. (2011) argue for the need to diversify the funding sources in order to achieve long-term financing rapidly, and if the private funds and other commitment funds (e.g. concessional loans, non-concessional loans and bonds) are excluded, it will not only dent the enthusiasm of developed countries, but also affect the rapid development and expansion of the GCF. However, developing countries argue that the financial contributions should be principally in the form of grants, and to the extent concessional finance is provided, only the grant or concessional element should be counted as "new and additional" (Stadelmann et al. 2011). Grubb (2011) believes that it would be a formidable challenge to raise such an amount of money, especially in the situation of economic recession; however, the revenue associated with charging for the carbon embodied in the international trade of carbon-intensive commodities is an attractive option. Vieweg (2013) argues that the four key criteria of contribution to paradigm shift, effectiveness, efficiency and sustainable co-benefits need to be assessed within an allocation framework of the GCF aimed at supporting transformational change. Müller et al. (2013) study whether the Quantity Performance Payments (QPPs) mechanism could be used for financing mitigation activities in developing countries in a 'direct access' way, and they argue that the QPPs can play a role in enhanced direct access first and foremost because they can be carried out in the absence of any information relating to operational funding decisions (such as project and programme approvals).

Second, some quantitative studies on the GCF have been conducted. For example, Silverstein (2013) proposes utilizing a harmonized carbon price to finance the GCF, where the financing is generated from transferring a percentage of the collected tax revenue, set according to historical emissions responsibility and national wealth. Then the collected revenue is disbursed on the basis of a set of national need factors for mitigation and adaptation. Hof et al. (2011) assesses four proposals –auctioning emission allowances, a tax on international aviation and shipping emissions, a global carbon tax, and an emissions trading levy to generate funds for the GCF – and find that the first two are the most promising financing proposals of the four. Carraro and Massetti (2012) estimate that 50% of the GCF in 2020 (USD50 billion) could finance an emissions reduction of 2.1 to 3.3 GtCO2-eq, depending on the domestic mitigation effort of the non-Annex II countries. Müller (2014) studies how to allocate the GCF among different receipt parties, and three resources allocation methods, the Performance-Based Allocation (PBA) system, the Resource Allocation Framework (RAF) system and the System for Transparent Allocation of Resources (STAR) system are introduced, and he argues that the choices in designing a formula for a measure or an index significantly influence the outcome and must be explicitly justified.

On the whole, the GCF has experienced a strong push since it was proposed. However, as a new concept, the GCF raises many concerns, the details of which remain unresolved. There are questions related to how the funds will be raised - who will pay and how; how the funds will be allocated; and how will the finance be allocated effectively - which need to be clarified (Bird et al. 2011, Hulme et al. 2011). Obviously, one of the most important reasons why the GCF has progressed slowly are the obstacles related to fund-raising and disbursement. As the benefactors, developed countries have no fund-raising schemes, and there is no satisfactory solution for enforcing the GCF responsibilities among developed countries; thus, financing the GCF is a tremendous challenge. Furthermore, as the recipients, developing countries have no reasonable disbursement schemes, and there is no solution for distributing the GCF among these developing countries; thus, distributing the GCF is also causing enormous difficulties.

GCF is likely to be the bone of contention of the UNFCCC negotiationspost-2012, and the issues regarding fund-raising and disbursement must be overcome before the working proposal for the GCF is put into practice. This paper focuses on the schemes and analysis of the GCF. Under the framework of the UNFCCC, Annex II countries are required to provide financial and technical support to developing countries to assist them in reducing their greenhouse gas emissions and in managing the effects of climate change (Lattanzio, 2013). Therefore, the paper operates on the assumption that the Annex II countries are the donors, while the non-Annex II countries are the recipients. The Annex II countries will negotiate the burden-sharing for financing the GCF, and then the collected funds will be distributed among the non-Annex IIcountries, according to their mitigation and adaptation activities. The rest of the paper is structured as follows: section 2 discusses how the Annex II countries will raise the GCF; section 3 discusses how the GCF will be distributed among the non-Annex IIcountries; section 4 presents a sensitivity analysis; finally, section 5 provides the discussion and conclusion.

2. How will the Annex II Countries Raise the GCF?

This paper operates on the assumption that the Annex II countries will be the contributors of long-term financing to the GCF. Annex II countries are a subset of Annex I parties. Different from non-Annex I parties, Annex I parties, listed in Kyoto protocol in 1997, are required to take quantified emission limitations and reduction objectives (QELROs). Annex II of the UNFCCC lists 24 parties: Australia, Austria, Belgium, Canada, Denmark, the European Economic Community, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom, and the United States.

At present, Annex II countries have no clear rules or trajectories for raising their climate-finance contributions. Instead, the fast-start contributions of USD 10 billion per year from 2010 to 2012 were collected through voluntary country pledges without clear modalities for distributing the contributions. While this approach may be considered pragmatic for providing modest short-term finance amounts, it could lead to disputes among donor countries and potential interruptions of contributions for greater amounts approaching USD 100 billion in the long term.

Establishing a clear method for allocating the finance responsibilities among Annex II countries may contribute to stabilizing the finance contributions. The final modalities of such an allocation method would be subject to negotiation among Annex II countries. In this paper, an allocation method based on environmental responsibility and economic capacity, with historical emissions as an indicator for environmental responsibility and GDP as indicator for economic capacity, will be used to guide such negotiations. Further, the population-based voting concept of preference score compromises (PSC), which was proposed by Müller (1999), could be used to aggregate both indicators. The structure of PSC is also in line with the provisions of the principle of 'Common but Differentiated Responsibilities and Respective Capabilities' affirmed by article 3.1 UNFCCC, and suggested by parties as a crucial element of climate finance architectures post-2012 (Paavola and Adger 2006, Müller and Mahadeva 2014).

2.1 Burden-haring based on the Historical Emissions Responsibility (HR) Approach

Allocating finance responsibilities in proportion to historical emissions is based on the idea that those countries which have contributed most to the current emissions levels and the resulting climatic change should bear most of the climate-finance responsibility. The historical emissions responsibility (HR) approach is based on the theory and notion of "polluters pay", which requires polluters to pay for damage done to the natural environment, and was first proposed by the OECD (OECD 1972). It has a long pedigree in climate change negotiations. One of the first contributions to the literature that actually elaborated on and quantified the notion of the HR was the proposal made by Brazil at the negotiations for the 1997 Kyoto Protocol (UNFCCC 2001). The HR has also been discussed extensively with regards to the development of appropriate burden-sharing schemes for future international climate change agreements (den Elzen et al. 2005, Baer 2013, Höhne et al. 2014) and in adaptation-focused studies (Dellink et al. 2009, European Commission 2009).

In this section, we estimate the allocation of climate-finance responsibilities based on the HR approach. In the HR approach, the burden-sharing for financing for each country is proportional to its cumulative carbon emissions. Three representative periods, 1850–2010, 1900

–2010 and 1990–2010, were chosen to investigate the impact of different historical periods on the results. As for the emissions sources, only CO_2 emissions from fossil fuels (LULUCF excluded) were considered. The regional CO_2 emissions data during the period 1850 to 2008 were obtained from Oak Ridge National Laboratory (Boden et al. 2012), while the 2009–2010 emissions data were derived from British Petroleum (2012). As some past emissions are only available on a regional basis and not country-by-country, we adopt regional growth rates to estimate country level emissions. In other words, we divide the regional emissions into the composite countries based on their current territory, and the carbon emissions for a country equals to its territory share multiplied by the regional total emissions, and territorial changes are not taken into account (Höhne et al. 2011). In this paper, the Annex II countries were divided into eight regions: the United States (USA), Japan (JPN), European Union (EU_27), Canada (CAN), Australia (AUS), New Zealand (NWZ), Switzerland (SWZ) and Norway (NOR).

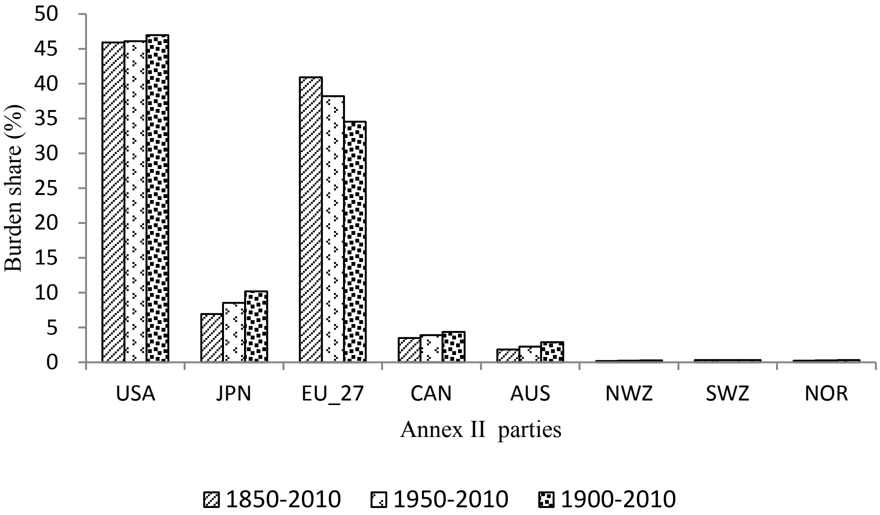

Fig. 1 Burden-sharing of financing the GCF based on HR

The cumulative carbon emissions of Annex II countries over the period 1850 to 2010 are about 772 $GtCO_2$ (Metric gigatons of CO_2). As shown in Figure 1, nearly 46% of all emissions are contributed by USA; thus USA is the largest contributor to the GCF. USA is followed by EU_27 with a share of 40%. In the case of HR, JPN should finance 7%. The financing shares of CAN and AUS are 4% and 2%, respectively. Changing the evaluation periods yields slightly different results. For example, using the 1990–2010 period increases Japan’s share to 10% and decreases the EU_27’s share to 35%. Because different countries typically have different emission peaks - and thus different historical response-bilities for different periods - the use of different historical periods leads to different financial burdens. Nonetheless, the USA and the EU_27 are consistently the two largest contributors to the GCF and collectively contribute more than 80% of the GCF, regardless of which evaluation period is used.

2.2 Burden-sharing based on the Respective Capability(RC) Approach

In addition to the principle of polluter pays, the principle of respective capability can also be an alternative for financing the GCF among donor countries. In the case of the RC approach, a country with higher respective capability will bear larger finance burden. The RC concept has also been applied in climate change research. Several contributions to the literature invoke RC with respect to allocating the mitigation burden among regions (Benndorf et al. 2007, European Commission 2009, Oberheitmann 2010, Mattoo and Subramanian 2012, Höhne et al. 2014). This principle has also been cited in discussions about how to enforce the adaptation funding requirements among different donor countries (Dellink et al. 2009, European Commission 2009, Grasso 2010).

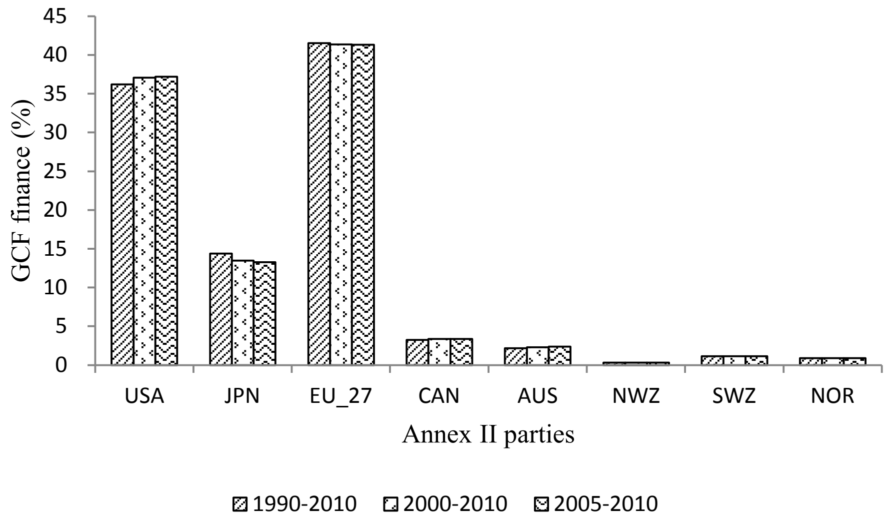

Fig. 2 Burden-sharing of financing the GCF based on RC

In this section, GDP is adopted as the RC index, implying that the country with the larger GDP will finance more. More specifically, in the RC approach, the burden-sharing for financing for each country is proportional to the national GDP. This concept has also been proposed by some countries for international climate finance. For example, China once stated that developed countries should annually provide financial support of no less than 0.5%

of their total GDP to support actions by developing countries to address climate change in developing countries (UNFCCC 2008). As in the HR analysis, three approaches were adopted to calculate GDP: regional average GDP during 1990–2010, regional average GDP during 2000–2010 and regional average GDP during 2005–2010. Regional GDPs have been sourced from the IMF website.

Table 2 presents the burden-sharing for financing under RC. As most developed countries have had stable economic growth since 1990, the regional GDP shares show little change in the three scenarios. In the RC approach, a larger GDP implies a higher finance share. Taking the period 1990–2010 as an example, the EU_27 is the largest contributor to the GCF, which sponsors 41% of the funds. This is followed by the USA with a share of 37%, and Japan, who should finance 14% of the GCF, which is almost twice of that in the HR approach.

2.3 Burden-sharing based on the preference score compromises (PSC) approach

Although the HR and RC could present alternatives for financing the GCF, the negotiations among the parties need to determine which alternatives to adopt; perhaps some countries prefer the HR approach, while others prefer the RC approach. To solve the conflicts between the parties, a politically legitimate and feasible approach is required to find the balance between HR and RC. This balance may be achieved by the PSC approach proposed by Müller (1999).

The traditional PSC method, which can be used to ascertain consensus in a multi-base distribution (e.g., grandfathering and per capita allocation), is based on a voting procedure that combines preferences for emissions rights allocation according to regional emissions levels or regional population levels. The Preference Score Share for each party is calculated by summing up the relative shares of either option weighted by the share of the world population preferring either the first or second approach (Müller 2001).

The PSC method was mainly used for discussing resource sharing in Müller's studies. However, the method can also be used to ascertain consensus in multi-base burden-sharing approaches. In this section, the PSC method is adopted as a means of balancing HR and RC to obtain a multi-base scheme for sharing the burden of financing the GCF. For the HR, the period 1850–2010 is chosen, as almost all the regional historical emissions from fossil fuels occurred in this period, and the calculation will not underestimate the historical responsibility for some regions. As for the RC, the case of regional average GDP throughout the period 1990–2010 is adopted.

Table 1 shows the results of the burden-sharing for financing the GCF under PSC. For the PSC approach, if a country prefers one alternative to the other, then the alternative will be scored, and the score is just the population of the country. Taking the USA as an example, it should finance 37.08% of the funds under RC, which is smaller than that in HR; thus, USA prefers RC to HR because the former will allow it to contribute less to the GCF.

Therefore, the RC approach receives 303.29 million votes, which is also the population of the USA. In contrast to the USA, JPN prefers HR to RC because the former will require it to contribute only 6.94% of the GCF; thus, the HR approach has 127.65 million votes, and so on. As shown in Table 1, almost 671.05 million people in Annex II countries prefer HR to RC, accounting for 67% of the total population; nearly 336.44 million people prefer RC to HR, accounting for 33% of the total population. As for the PSC approach, the burden-sharing is based on a population-weighted preference for HR and RC. For example, the share for the USA is 42.97%=67%·45.92%+33%·37.08%. In the case of PSC, the EU_27 and the USA are the two largest contributors to the GCF, sponsoring more than 80% of the funds. This is followed by JPN, with a share of 9%.

Table 1 Sharing the burden of financing the GCF based on the PSC approach

	Alternatives		Voting process*		Results
	HR (%)	RC (%)	Vote for HR* (Million)	Vote for RC* (Million)	Burden-sharing(%)
USA	45.92	37.08	0.00	303.29	42.97
JPN	6.94	13.51	127.65	0.00	9.13
EU_27	40.93	41.36	505.21	0.00	41.07
CAN	3.51	3.37	0.00	33.15	3.46
AUS	1.88	2.31	21.52	0.00	2.02
NWZ	0.22	0.33	4.26	0.00	0.26
SWZ	0.33	1.14	7.66	0.00	0.60
NOR	0.27	0.91	4.75	0.00	0.49
Score	-	-	671.05	336.44	100.00

Note：*Regional average population over the period 2000 –2010 is from the IEA (2012).

3. How to Spend the GCF among the Non-Annex II Countries?

This section focuses on the distribution of the GCF among the non-Annex II countries. Ideally, the distribution approaches should be designed based on the dual purpose of the GCF: climate mitigation and climate adaptation. For the adaptation purpose, this paper focuses on the allocation fairness of the funds, and that the most vulnerable countries should be given priority for the funds allocation. For the mitigation purpose, this paper focus on abatement efficiency and two approaches are proposed. The first one is the carbon reduction contribution (CC) approach, which provides some profits for the mitigating countries. The country with large mitigation will be rewarded by receiving more funds, thus this approach will give full play to the initiative for developing countries to control their carbon emissions. The other one is the incremental cost (IC) approach, in which the GCF pays exactly the marginal abatement costs of the projects, thus there is no surplus profit to mitigating countries.

The concept of the IC has been used in the

Global Environment Facility (GEF) allocation (GEF 2007). Nonetheless, the system for transparent allocation of resources (STAR) approach for the GEF cannot be used for the GCF distribution directly for the following reasons. Firstly, the two funds have different objectives. Compared with the dual purpose of the GCF, the GEF provides grants for projects related to biodiversity, climate change, international waters, land degradation, the ozone layer, and persistent organic pollutants (GEF 2007). Due to the different objectives, the distribution approaches for the two funds could also be different. Secondly, the STAR approach belongs to the performance-based allocation system, which allocates the funds based on the project performance (GEF 2007). This approach may cause some difficulties for achieving the adaptation purpose of the GCF, as adaptation presents a range of uncertainties that makes evaluation particularly challenging.

The non-Annex II countries are divided into seven regions in this paper: China (CHN), India (IND), other Asia economics (OAS), Central and South America (CMS), the Middle East (MES), African economics (AFR) and the Rest of the World (ROW). It should be noticed that Russia, which is one member of the Annex I parties, could also obtain some financial support from the GCF in our analysis. This paper will adopt data from the MIT Emissions Predictions and Policy Analysis (EPPA) model to study the distribution effects of the funds. In the EPPA model, Russia is not a separate region and it was disaggregated into the Former Soviet Union, which was defined as ROW in this research. The focus here is on the allocation effects of the GCF at USD 100 billion per year, and the financing level is also discussed in other studies (e.g. Stadelmann et al. 2011, Silverstein 2013, Springmann 2013). The mitigation effects of the GCF with more finance levels can be found in section4.4.

3.1 Distribution of the GCF based on Regional Adaptation Fairness

With limited resources and great sensitivity to climate change, developing countries are in great need of financial support for combating their adverse effects of climate change. One study by the Word Bank shows that the adaptation costs for developing countries approaches USD70–100 billion per year for 2010–2050 (Narain et al. 2011). How to allocate the GCF in a fair and equitable way is a crucial issue that needs to be solved. Intuitively, if promoting climate adaptation is the main purpose of the GCF, it would be reasonable if the funds were distributed according to regional adaptation needs. It is necessary to provide sufficient financial support and technology transfers to the most vulnerable countries that are ill-equipped to combat climate change, in particular the Least Developed Countries (LDCs) and African States (see, e.g., paragraph 17 in Modalities for Readiness and Preparatory Support, GCF/B.05/14). This section discusses the distribution of the GCF on the basis of regional adaptation fairness. Before that, an index will be constructed to reflect the degree of adaptation needs for each non-Annex II party.

One can imagine that the adaptation needs of a country depend not only on its economic strength but also on the climate damage it suffers. On the one hand, climate vulnerability is not evenly distributed, and the greatest vulnerability lies in developing countries with less historical emissions, especially for the small island countries. Therefore, the adaptation index needs to reflect the heterogeneity of climate losses, and the countries which are more vulnerable should have a stronger claim on adaptation resources. On the other hand, different non-Annex II parties usually have different national wealth and thus experience different adaptation capabilities. Compared to the poorer countries, the richer countries may have more resources to combat climate change and thus face fewer funding gaps in climate adaptation. Therefore, the adaptation index needs to embody the heterogeneity of regional economic strength.

This paper constructs the adaptation-needs index by taking into account regional GDP and regional climate losses. GDP is considered to represent national wealth, and a country with a large GDP may have more resources to combat climate change. Let Θ denote the set of non-Annex II regions; thus, Θ={CHN,IND, MEX,ASI,CMS,SAF,ROW}. Assume D_i is the climate damage and GDP_i is the corresponding GDP. The self-adaptation capability β_i in this paper is defined as,

$$\beta_i = GDP_i / D_i . \tag{1}$$

The index β_i tells us how many units of GDP are available to address one unit of climate damage, thus measuring the difficulty for *i* to address its climate damages. As Eq. (1) indicates, the country with larger GDP and fewer climate losses will have a higher self-adaptation capability. Similarly, the average self-adaptation capability of non-Annex II countries ϖ is defined as

$$\varpi = (\sum_{i\in\Theta} GDP_i) / (\sum_{i\in\Theta} D_i)$$

which represents how many units of GDP are available to address one unit of climate damage at the aggregated level. ϖ can be used to investigate the degree of the adaptation needs for each developing party. Also, regional adaptation needs α_i is expresses as,

$$\alpha_i = D_i\varpi - GDP_i . \tag{2}$$

As Eq. (2) shows, $D_i\varpi$ is the GDP needed for region *i* to address climate change in the average self-adaptation level of the non-Annex II countries, and GDP_i is the corresponding GDP at present; thus, α_i is the GDP gap for *i*. A larger α_i implies that the country is lacking more money to address its climate damages and should thus be prioritized in the allocation of funds, while a smaller α_i indicates that the country may have more resources and should thus be allocated less funds. Clearly, this definition has the advantage of simplicity and transparency. α_i can be positive or negative, and if it is negative, it cannot be used directly for the GCF distribution. Using a normalization method, γ_i is equal to α_i minus the smallest value, and the GCF share ε_i is expressed as follows:

$$\gamma_i = \alpha_i - \min_{k\in\Theta} \alpha_k . \tag{3}$$

$$\varepsilon_i = \gamma_i / \sum_{k\in\Theta} \gamma_k . \tag{4}$$

For the empirical analysis, it is necessary to identify the climate loss for each country. It should be mentioned that the accurate estimation of climate damages for a country is extremely difficult and complex, and we adopt the results released by German watch to finish the empirical analysis due to data availability. More specially, Harmeling and Eckstein (2012) study to what extent countries have been affected by climate change, and they adopt the most recent available data concerning weather-related loss events (e.g. storms, floods, heat waves, etc.) for the period 1992–2011, and give a quantitative evaluation of the direct economic loss for each country over the past 20 years. The results reconfirm that developing countries are generally more affected than developed countries, although the research does not consider climate losses resulting from other aspects, such as rising sea levels, melting glaciers or more acid and warmer seas. In this research, we will use this most regional-detailed database to give a preliminary evaluation of the AN approach. As climate damages provided by Harmeling and Eckstein (2012) are measured in USD in purchasing power parity (PPP), regional average GDP for 2008–2012 in PPP is adopted for consistency.

Table 2 shows the allocation effect of the GCF under the AN approach (for more details, please refer to Table A1). As shown, the total weather-related loss each year in the non-Annex II countries is about USD 68.17 billion (in PPP), 40.80% of which is contributed by CHN. Though CHN experiences the largest loss, it is only able to obtain 2.62% of the GCF due to its large national GDP. On the contrary, with lower GDP levels, nearly 30% of the funds will be obtained by African economies, though AFR only experiences 1.89% of climate damages. AFR is followed by CMS and OAS, receiving 22.92% and 19.95% of the funds, respectively. In sum, the African economies could obtain the most adaptation finance, thus the AN index constructed in this paper embodies some spirit of fairness, as African economies usually experience higher climate vulnerability than other developing regions (Barr et al. 2010, DARA and the Climate Vulnerable Forum 2012).

3.2 Distribution of the GCF based on Carbon Reduction Contribution

Climate mitigation is another purpose of the GCF. Developed countries could positively influence fairness perception in developing countries by providing climate finance, and the improved fairness perception in poor countries could in turn improve the prospects of success of international negotiations on climate change mitigation (Pittel and Rübbelke 2013). Indeed, the Copenhagen Accord and the Cancun Agreements set conditions for developed countries' contributions to long-term climate finance regarding 'meaningful mitigation action and transparency on implementation' (see, e.g., paragraph 98 in the Cancun Agreements, FCCC/CP/2010/7/Add.1). Here we introduce two distribution approaches for the mitigation purpose of the GCF. The first one is the carbon reduction contribution (CC) principle, in which a country with large mitigation will be rewarded by receiving more funds. In the case of CC, the fund's distribution satisfies the following order: firstly, the non-Annex II parties make some commitments of emissions reduction; secondly, the GCF is distributed on the basis of regional mitigation commitments; thirdly, an inspection is undertaken by a third party to check whether developing parties have achieved their abatement commitments, and if not, some punishment measures are introduced. The other one is the incremental cost (IC) principle, which has been used for allocation by the Global Environment Facility. In the case of the IC approach, GCF pays exactly the marginal abatement costs of the projects, thus there is no surplus profit to mitigating countries (GEF 2007). It should be noted that the CC and IC approaches have not considered the emissions reduction from the previously projects funded by developed countries.

Table 2 Allocation effect of the GCF based on the AN approach

	D_i (Billion \$ PPP)	D_i shares(%)	β_i (USD)	ε_i (%)
CHN	27.81	40.80	367.56	2.62
IND	6.46	9.48	621.40	0.45
OAS	16.28	23.88	340.67	19.95
AFR	1.29	1.89	1386.62	29.35
MES	3.45	5.06	1192.00	13.88
CMS	8.59	12.60	766.00	22.92
ROW	4.31	6.32	708.71	10.82
Non-Annex II	68.17	100.00	517.76	100.00

Note: Regional direct losses are from Harmeling and Eckstein (2012); regional GDP are from IMF website.

3.2.1 The Concept of Carbon Reduction Contribution

A simple model is used to illustrate the CC concept. Assuming that there are *N* developing countries (regions) to share the GCF, the marginal abatement cost function for *i* is $C_i(A_i)$, where A_i is the emissions reduction. The marginal abatement cost reflects the additional costs of reducing the last unit of CO_2 and is upward sloping. Integrating the marginal abatement cost function yields the total abatement cost for *i* to reduce

$$A_i : \int_0^{A_i} C_i(x)dx .$$

Let *W* denote the level of the GCF; thus, the fund obtained by country *i* will be

$$\frac{A_i W}{\sum_k A_k}$$

Also, country *i* will choose the optimal reduction to maximize its profit π_i,

$$\pi_i = \frac{A_i}{\sum_k A_k} W - \int_0^{A_i} C_i(x)dx . \quad (5)$$

The first order conditions, $\partial \pi_i / \partial A_i = 0$, yields,

$$\frac{\sum_{k \neq i} A_k}{(\sum_k A_k)^2} = C_i(A_i) \quad i = 1, 2, \cdots, N . \quad (6)$$

It is possible to calculate the actual reduction level for each participant by establishing simultaneous equations from Eq. (6). The left side of Eq. (6) represents the marginal abatement benefit (*MAB*), which denotes the GCF obtained when more abatement is undertaken; the right side of Eq. (6) represents the marginal abatement cost (*MAC*), which denotes the economic burden when more emissions are reduced. It should be noted that the CC approach has not taken environment benefits of emissions reduction into account due to data availability, as one country's mitigation will result in global benefits, and the estimation of the environment benefits for a particular country is subject to great uncertainties.

The benefit and cost analysis of the CC approach is displayed in Figure 3. The intersection of the two curves represents the equilibrium point, implying that the marginal abatement benefit equals the marginal abatement cost. Therefore, the area OAB represents the total abatement cost, OABC is the climate funds obtained, and OBC is equal to the mitigation profit π_i. In the CC approach, a country with less marginal cost will earn more mitigation profits. Moreover, with a higher *W*, the profit obtained by some regions can be several times that of the abatement cost. The concept of CC is intuitive and simple, and the developing countries could obtain some profits through mitigation activities, and the profits can be used to finance adaptation activities domestically. Therefore, the CC approach respects the initiative for developing countries to control their carbon emissions.

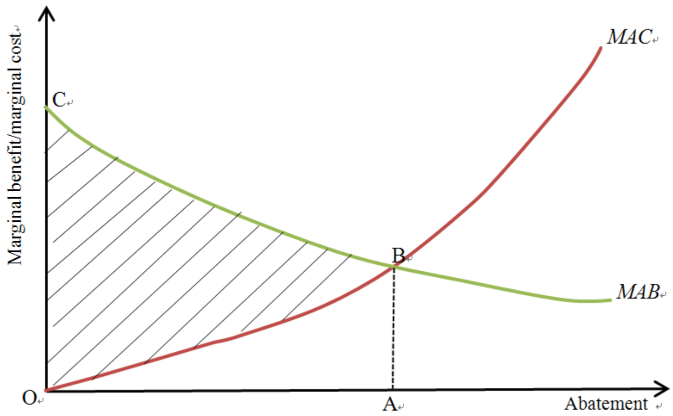

Fig. 3 Benefit and cost analysis for the CC approach

3.2.2 The Concept of Incremental Cost Principle

Different from the concept of CC, the incremental cost (IC) principle requires that the GCF should be paid exactly the marginal abatement costs of the projects, thus there is no profits for mitigating countries. The concept of incremental cost is from the GEF allocation, which states that "the GEF⋯shall operate for the purpose of providing new and additional grant and concessional funding to meet the agreed incremental costs of measures to achieve agreed global environmental benefits" in the GEF focal areas (GEF 2007). In the case of the IC approach, the GCF will "exhaust" the cost-effective abatement opportunities and, depending on its design, may result in the same marginal abatement costs for all developing parties. Assuming the equilibrium carbon price is t , and we have,

$$C_i(A_i) = t, \quad i = 1, 2, \cdots, N. \tag{7}$$

When the market equilibrium occurs, the amount of the GCF should be equal to the total abatement cost,

$$\sum_{i=1}^{N} \int_0^{A_i} C_i(x)dx = W . \tag{8}$$

The carbon emissions reduction for all developing parties can be obtained from Eq. (7) and Eq. (8). It can be seen that the total abatement in the IC approach will be larger than that in the CC approach, as in the former, all money is spend on mitigation activities with no mitigation profits. However, the application of the incremental cost principle may be complex and not always transparent (GEF 2007).

3.2.3 Regional Marginal Abatement Costs Estimation

To evaluate the distribution effect of the GCF based on the CC and IC approaches, we adopt marginal abatement cost functions from the MIT Emissions Predictions and Policy Analysis (EPPA) model (Morris et al. 2012). The EPPA model contains a detailed representation of the energy sector and emissions control options for CO_2 and other non-CO_2 greenhouse gases. Including EPPA's MAC curves therefore enables a detailed representation of developing countries' marginal abatement costs. This study parameterizes EPPA's MAC curves by a polynomial of second degree (see, e.g., Böhringer et al. 2005, Anger 2008, Springmann 2013; also see Table A2 in the appendix for a summary of the fit parameters obtained in this way).

The MAC curve represents an economy's optimal response to alternative carbon prices, including moving away from coal and towards gas in electricity production, improving energy efficiency, using non-fossil energy and reducing energy demand. While national climate policies may trigger some of those responses, they are unlikely to induce all of them in an economically optimal distribution. Previous studies that have aimed at estimating the availability of emissions reductions in developing countries have scaled back the emissions reduction potential derived from MAC curves in various ways, for example, by inserting transaction costs and assuming practical abatement that is a fraction of the economy-wide MAC estimate (den Elzen&Both 2002, Jotzo and Michaelowa 2002, Michaelowa and Jotzo 2005, Hof et al. 2009, Eisenack 2012).

This paper follows the modelling of emissions trading and abatement costs in the FAIR 1.1 model developed by den Elzen and Both (2002) and adopted by Hof et al. (2009). Specifically, to avoid overestimation, the practical abatement potential is assumed to be 20% of the total potential, and transaction costs (which are assumed to be proportional to the abatement costs) are assumed to be 3.5% according to a project-level review of abatement potential in developing countries (Wetzelaer et al. 2007).

3.2.4 Distribution Effects of the GCF

Table 3 lists the regional mitigation profits and abatement potentials obtained under the CC approach. As shown, USD 100 billion is estimated to induce the non-Annex II countries to reduce their emissions by 2031 $MtCO_2$, accounting for nearly 13% of the total emissions in the non-Annex II countries in 2010. Among others, CHN has the greatest abatement potential, contributing almost 30% of all abatement. As a result, CHN would also receive nearly 30% of the funds. This is followed by ROW (in particular, non-Annex II countries in Eastern Europe) and CMS, who will receive 16.62% and USD 12.73% of the funds, and AFR and MES, receiving less than 10% of the funds.

Table 3 Regional abatement potential, its costs and finance flows in the CC approach

	Abatement ($MtCO_2$)	GCF obtained (%)	Mitigation profits (USD billion)	Abatement costs (USD billion)	Average abatement cost (USD/tCO_2)
CHN	593	29.19	23.16	6.03	10.17
IND	230	11.31	8.26	3.05	13.26
OAS	348	17.14	11.88	5.26	15.10
AFR	168	8.26	5.65	2.61	15.54
MES	97	4.76	3.01	1.76	18.14
CMS	258	12.73	9.14	3.59	13.89
ROW	338	16.62	11.45	5.17	15.30
Total	2031	100.00	72.55	27.45	13.51

As shown, the total abatement costs for these regions are less than one third of the total mitigation profits in most regions. This is a direct result of the profit maximization setup of the CC approach (see Figure 3). The average abatement cost amounts to 14 USD/tCO_2, which is comparable to the prices for Certified Emissions Reductions (CERs) until 2010 under the Clean Development Mechanism (CDM) of the Kyoto Protocol. It should be noted that Table 3 only provides the initial effects of the GCF distribution based on the CC approach. The marginal abatement costs of developing parties will increase when more abatement is undertaken and the mitigation profits under the CC approach will be gradually reduced over time. As shown in Figure 4, if we do not consider natural technological progress, nearly 73% of the funds are mitigation profits in 2020 (see Table 3), and the share is estimated to decrease to 40% in 2021 and 30% in 2022, and so on. Therefore, after six periods, the mitigation profits only account for 20% of the GCF, which implies that nearly 80% of the funds are abatement costs.

Table 4 lists distribution effects of the GCF based on the IC approach. As shown, the amount of USD 100 billion is estimated to induce the non-Annex II countries to reduce their emissions by 3118 $MtCO_2$, with an increase of 54% compared to the result under the CC approach. Among others, nearly 27% of the funds are used to finance China to reduce national emissions by 936 $MtCO_2$, accounting for 30% of all abatement. Almost 10% of the funds are used in India, and the national emissions are reduced by 330$MtCO_2$, which is almost one third of that for China. Different from the emerging economies, only 7.95% of GCF is used in Africa, which contributes an emissions reduction of 246 $MtCO_2$, as Africa generally has low abatement potentials.

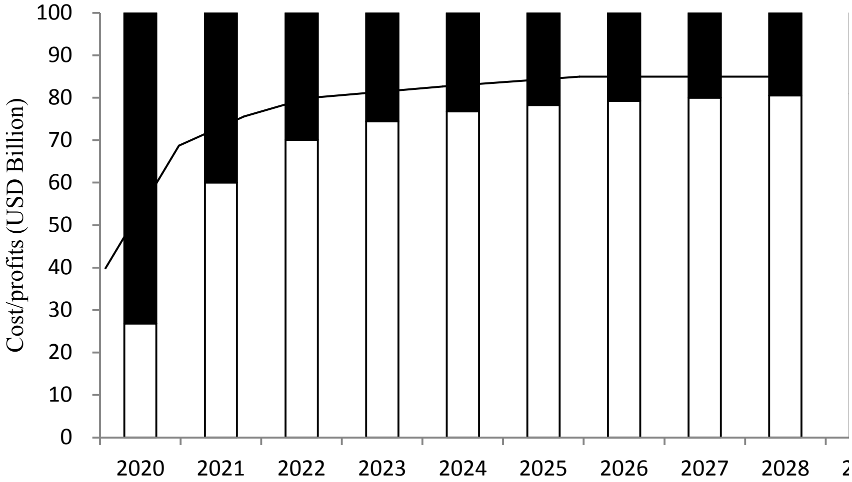

Fig. 4 The changes of abatement costs and mitigation profits under CC with the GCF at USD 100 billion

Table 4 Distribution effects of the GCF under the Incremental Cost Principle

	Abatement ($MtCO_2$)	Abatement Share(%)	GCF obtained (%)	Average abatement cost (USD/tCO_2)
CHN	936	30.02	27.45	29.33
IND	330	10.58	9.81	29.76
OAS	558	17.89	20.32	36.44
AFR	246	7.88	7.95	32.34
MES	146	4.67	5.16	35.40
CMS	366	11.73	10.94	29.91
ROW	537	17.23	18.38	34.20
Total	3118	100.00	100.00	32.07

The comparison between Table 3 and Table 4 results in some interesting findings. For example, although the CC and IC approaches have different mitigation profits and different abatement effects, the GCF obtained for each region in the two approaches changes minimally. In particular, CHN gets the most mitigation finance because it has the greatest abatement potential. CHN has been a dominant player in CDM markets with approximately 50% of the world's 4768 CDM projects since 2005, which is evidence of CHN's great potential for actual emissions reduction (Maraseni 2013). In all, AFR could obtain limited funds, approaching 8% of the GCF, which is less than one third of that in the AN approach (see Table 2).

3.3 Distribution Effect of the GCF based on the Composite Approach

Regional adaptation fairness and abatement efficiency should be considered together to achieve the two purposes of the GCF reasonably: climate mitigation and climate adaptation. In that regard, the Fifth Meeting of the Board of the GCF points out that the allocation should increase the mitigation impact of the available resources while ensuring the adaptation fairness to the affected countries (see paragraph 29 in Business Model Framework: Allocation, GCF/B.05/05). For the CC or IC approaches, overconcentration on the abatement efficiency of the GCF may overlook the adaptation needs of the poorer regions with lower abatement potentials. Similarly, the simple AN approach does not consider the reduction effect of the GCF, which curbs the Annex II countries' enthusiasm about financing. Therefore, balancing allocation between mitigation and adaptation requires a reasonable combination of the AN and CC (or IC) approaches.

Regarding the allocation of available financial resources between climate mitigation and climate adaptation, this paper takes into account the information of the Meeting of the Board of the GCF. The Seventh meeting of the Board held on February 2014 states that "the Board decide to aim for a 50:50 balance between adaptation and mitigation during the initial phase of the Fund" (see paragraph 42 in Initial Modalities for the Operation of the Fund's Mitigation and Adaptation Windows and its Private Sector Facility, GCF/B.07/08). In line with this reasoning, this paper introduces two composite approaches, depending on how to achieve the mitigation purpose of the GCF. The first one is the ANCC approach, which requires that the distribution is an equal spilt between the AN and CC approaches. The other one is the ANIC approach, which requires that half of the GCF will be distributed based on the AN approach and half of the funds will be distributed based on the IC approach. More allocation scenarios will be discussed in the sensitive analysis.

3.3.1 The Distribution Effects of the GCF based on ANCC

The distribution effects of the GCF based on the ANCC approach are presented in Table 5. As shown, the amount of USD 100 billion is estimated to induce developing countries to reduce their emissions by 1613 $MtCO_2$, accounting for nearly 10% of the total emissions in the non-Annex II countries in 2010. Among others, CHN reduces national emissions by 482 $MtCO_2$, contributing almost 30% of all abatement, which is the largest of all contributions. As a result, 16.25% of the GCF will be obtained by CHN. In the ANCC approach, the African countries obtain USD 18.77 billion. This is followed by OAS and CMS who receive USD 18.40 billion and USD 17.93 billion, respectively. IND obtains USD 5.99 billion, almost one third of that of CMS, which is the smallest of amount.

Table 5 The distribution effects of the GCF based on ANCC

	Abatement ($MtCO_2$)	GCF obtained (USD billion)	Abatement costs (USD billion)	Adaptation funds (USD/tCO_2)	Per capita adaptation funds (USD)*
CHN	482	16.25	2.92	13.33	9.89
IND	186	5.99	1.50	4.48	3.71
OAS	272	18.40	2.40	16.00	15.32
AFR	132	18.77	1.30	17.46	23.57
MES	73	9.21	0.86	8.35	21.23
CMS	209	17.93	1.78	16.16	27.97
ROW	260	13.45	2.57	10.88	44.56
Total	1613	100.00	13.34	86.65	15.60

Note: *Regional average population over the 2005 –2010 period is from the IEA (2012).

Countries with large climate funds usually have more funds for adaptation. Here, the adaptation funds under the ANCC approach are defined as the adaptation funds under the AN approach plus the mitigation profits under the CC approach. More specially, AFR could obtain USD 17.46 billion, which is the largest amount. This is followed by CMS and OAS who obtain USD 16.16 billion and USD 16 billion, respectively. As shown in Table 5, although ROW countries (in particular, non-Annex II countries in Eastern Europe) do not have large adaptation funds, its per capita adaptation funds (USD 44.56) are quite high due to the small population. Differently, with a large population, the per capita adaptation funds for IND are USD 3.71, which is the smallest amount. The per capita adaptation funds for non-Annex II parties are about USD 15.60 on average, which is larger than those of CHN (USD 9.89) but smaller than those of AFR (USD 23.57).

3.3.2 The Distribution Effects of the GCF based on ANIC

The distribution effects of the GCF based on the ANIC approach are presented in Table 6. As shown, USD 100 billion of the GCF could finance an emissions reduction of 2477 $MtCO_2$, with an increase of 54% compared to the result under the ANCC approach. Among others, CHN, with the greatest abatement potential, reduces its carbon emissions by 766 $MtCO_2$, contributing almost 31% of all abatement; IND reduces its emissions by 269 $MtCO_2$, contributing almost 11% of all abatement. Although the ANCC and ANIC approaches have different mitigation effects, the GCF obtained for each region in the two approaches changes minimally. For example, the funds obtained by CHN increase slightly from USD 16.25 billion under the ANCC approach to USD 16.78 billion under the ANIC approach, whereas those for AFR decrease slightly from USD 18.77 billion to USD 18.65 billion.

Table 6 The distribution effects of the GCF based on ANIC

	Abatement ($MtCO_2$)	GCF obtained (USD billion)	Abatement costs (USD billion)	Adaptation funds (USD billion)	Per capita adaptation funds (USD)
CHN	766	16.78	14.27	2.50	1.86
IND	269	5.66	5.11	0.55	0.45
OAS	410	18.25	8.57	9.68	9.26
AFR	197	18.65	4.15	14.50	19.57
MES	114	9.23	2.66	6.57	16.71
CMS	298	17.48	5.69	11.78	20.40
ROW	423	13.96	9.54	4.41	18.08
Total	2477	100.00	50.00	50.00	9.00

Note: *Regional average population over the 2005 –2010 period is from the IEA (2012).

As shown, AFR gets most adaptation funds, that is, USD 14.50 billion, followed by CMS, at USD 11.77 billion. Different from the results under the ANCC approach, the adaptation funds for the emerging economies have decreased drastically under the ANIC approach. For example, CHN's adaptation funds decrease from USD 13.33 billion to USD 2.50 billion, while those for IND decrease from USD 4.48 billion to USD 0.55 billion. As the incremental cost principle offers no surplus profits for mitigating countries, the adaption funds obtained by each region under the ANIC approach were determined by the allocation results under the AN approach. This is quite different from the results under the ANCC approach, in which the emerging economics could earn mitigation profits by reducing their carbon emissions. As shown in Table 6, the per capita adaptation funds vary from USD 0.45 (IND) to USD 20.40 (CMS), with an average level of USD 9.00 in non-Annex II parties. African countries also get a high level of per capita adaptation funds, with the amount of USD 19.57, which is almost ten times of that for CHN.

4 Sensitivity Analysis

4.1 The Coverage of the GCF Finance

As discussed before, it was assumed that all Annex II countries will negotiate sharing the burden of GCF financing. Other developed countries, such as South Korea and Israel, will receive climate funds, as they do not fall in the Annex II classification. However, providing financial support to address the needs of developing countries is a long-term issue. As the international climate finance regime continues to develop, it will be an attractive option to include more countries to finance the GCF to provide sufficient financial support for developing countries rapidly. Therefore, it may be reasonable to include the developed countries which are not Annex II parties to share some finance burden. In this section, we extend the donor countries of the GCF, by some OECD members that are not listed as Annex II parties (OOECD), such as South Korea, Mexico, Israel and Chile, to contribute to financing the

GCF. The data sources of the new scenario are the same to those in the base case.

As shown in Table 7, the new burden-sharing arrangement causes the EU_27 to change its preference from the HR approach to the RC approach. In total, almost 344 million votes are cast for the HR approach, which accounts for 29% of the total population, whereas nearly 842 million votes are cast for the RC approach, which accounts for 71% of the total population. Therefore, the preferences for the two alternatives have thus changed dramatically. Compared to the results in the base case, under the new scenario, the USA's financing share decreases from 42.97% to 36.88%, and the EU_27's share decreases from 41.07% to 38.27%. Differently, nearly 10.70 % of the funds should be provided by Japan, which represents a slight increase relative to the base case. Regarding the newcomer, OOECD should finance 7.19% of the funds. However, the burden for most of the countries does not change much. For example, USA and EU_27 are still the two largest contributors to the GCF, sponsoring more than 75% of the funds. JPN follows with almost 10%.

Table 7 Sharing the burden based on the PSC approach with alternative coverage of the GCF

	Alternatives		Voting process*		Results	Previous coverage
	HR (%)	RC (%)	Vote for HR* (Million)	Vote for RC* (Million)	Burden-sharing (%)	Burden-sharing (%)
USA	44.19	33.89	0.00	303.29	36.88	42.97
JPN	6.68	12.35	127.65	0.00	10.70	9.13
EU_27	39.40	37.80	0.00	505.21	38.27	41.07
CAN	3.38	3.08	0.00	33.15	3.17	3.46
AUS	1.81	2.11	21.52	0.00	2.02	2.02
NWZ	0.21	0.30	4.26	0.00	0.28	0.26
SWZ	0.32	1.04	7.66	0.00	0.83	0.60
NOR	0.26	0.83	4.75	0.00	0.66	0.49
OOECD	3.75	8.59	178.58	0.00	7.19	-
Score	-	-	344.42	841.65	100.00	100.00

Note：*Regional average population over the 2000 –2010 period is from the IEA (2012).

4.2 Alternative Accounting Base for RC

The second sensitive analysis focuses on an alternative accounting base for the RC approach.

Different from the historical simulation in Section 2.2, we consider a forward looking case here. More specially, regional GDPs thought 2010-2020 from IMF projection are used to discuss the distribution effects of the GCF based on the RC and PSC approaches. As we can see from Table 8, compared with the results in the base case (see Table 1), regional financing burdens under the RC approach have not changed drastically in the new accounting base. For example, the USA's financing share increases from 37.08% to 38.84%, whereas Japan's share decreases from 13.51% to 12.72%.

Different from other regions, in the forward looking case, the EU_27 changes its preference from the HR to the RC approach. As a result, almost 199 million votes are cast for the HR approach, which accounts for 20% of the total population, whereas nearly 809 million votes are cast for the RC approach, which accounts for 80% of the total population. Compared with the results in Table 1, under the new scenario, the USA's financing share decreases from 42.97% to 40.24%, and the EU_27's share decreases from 41.07% to 39.97%. Differently, nearly 11.58 % of the funds should be provided by Japan, with a moderate rise compared with the base case. In sum, the burden for most of the countries does not change much. The USA and the EU_27 are still the two largest contributors to the GCF, sponsoring nearly 85% of all finance.

Table 8 Sharing the burden based on the PSC approach with alternative GDP accounting base

	Alternatives		Voting process*		Results	Previous coverage
	HR (%)	RC* (%)	Vote for HR* (Million)	Vote for RC* (Million)	Burden-sharing (%)	Burden-sharing (%)
USA	45.92	38.84	0.00	303.29	40.24	42.97
JPN	6.94	12.72	127.65	0.00	11.58	9.13
EU_27	40.93	39.73	0.00	505.21	39.97	41.07
CAN	3.51	3.55	33.15	0.00	3.54	3.46
AUS	1.88	2.68	21.52	0.00	2.52	2.02
NWZ	0.22	0.37	4.26	0.00	0.34	0.26
SWZ	0.33	1.19	7.66	0.00	1.02	0.60
NOR	0.27	0.92	4.75	0.00	0.79	0.49
Score	-	-	198.99	808.50	100.00	100.00

Note *: Regional average GDP throughout 2010–2020 is from the IMF (2014).

4.3 Different climate damages estimation

In Section 3.1, the regional climate damages from German watch were used to capture the distribute effects of the GCF under the AN approach. For the sensitive analysis, we adopt the 2010 climate change impact cost estimates recently published in the second edition of the Climate Vulnerability Monitor (CVM2). Different from Germanwatch's global climate risk index (CRI), which calculates nations' vulnerability in terms of historical fatalities and economic losses due to extreme weather events, DARA's Climate Vulnerability Monitor evaluates the global impact of climate change on human health, weather, human habitat, and economics at a national level (DARA and the Climate Vulnerable Forum, 2012).

The distribution effects are presented in Figure 5. As we can see, although regional climate damages are not identical, the two scenarios have similar distribution results under the AN approach. For example, nearly 30% of the funds are allocated to AFR, which is the largest allocation. This is followed by CMS and OAS, with a share of 23% and 19%, respectively. The Middle East obtains almost 14% of the GCF, which is slight larger than

11% for ROW. For the emerging economics, CHN and IND obtain limited adaptation finance, less than 3% of the total finance.

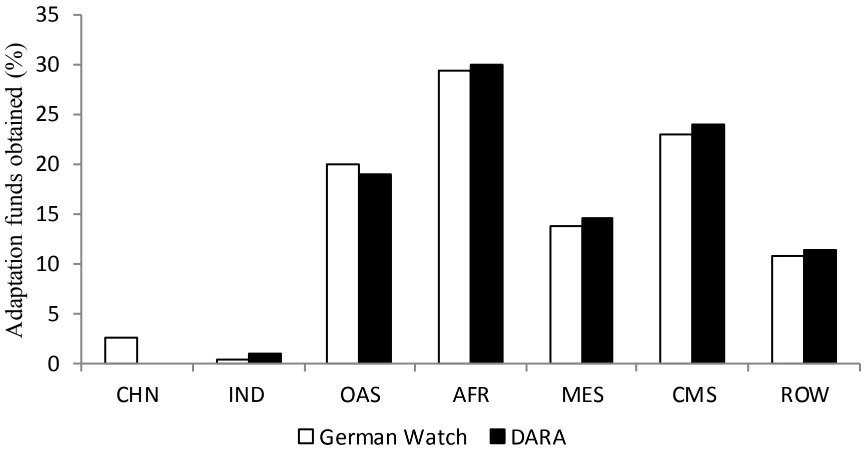

Fig. 5 The distribution of the GCF in AN approach with different climate damages estimation

4.4 Different Allocation of the GCF Between Mitigation and Adaptation

The above analysis operates on the assumption that the GCF will achieve a 50:50 balance between adaptation and mitigation. We relax this assumption for this sensitive analysis. More specially, five cases about the GCF allocation are considered for the simulation, and we assume 10%, 30%, 50%, 70% and 100% of the funds will be used for the mitigation purpose. As there are two approaches for combining abatement efficiency and adaptation fairness (AN+CC or AN+IC), we obtain ten scenarios in total. Figure 6 illustrates the regional carbon emissions changes with different mitigation parameters. As shown, if more funds are used for climate mitigation, all regions will further reduce their emissions, but the regional mitigation contributions change minimally. For example, in the case of AN+CC, with the mitigation parameter increases from 10% to 100%, the total abatement of non-Annex II countries will increase from 959 $MtCO_2$ to 2031 $MtCO_2$. Among others, CHN is always the largest contributor, sponsoring for 30% of all abatement. OAS follows with a share of 17%. Additionally, nearly 4% of the total abatement was provided by MES, which is the smallest abatement. As shown in Figure 5, the AN+IC approach could result in more mitigation than the AN+CC approach: the former is 54% larger than the latter, regardless of the value of mitigation parameter.

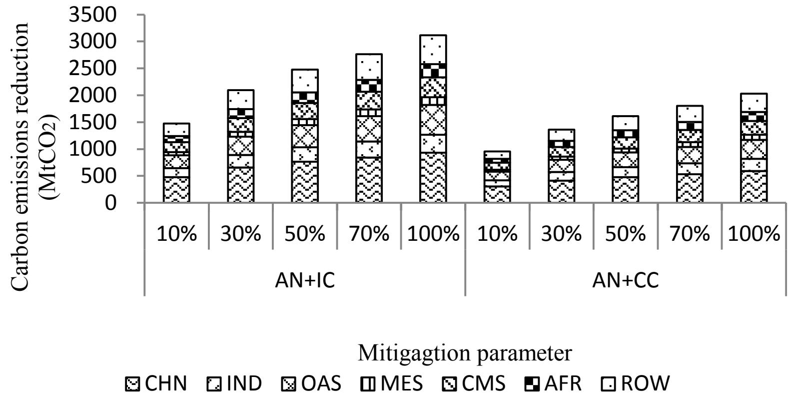

Fig. 6 Regional carbon emissions reduction with different mitigation parameters

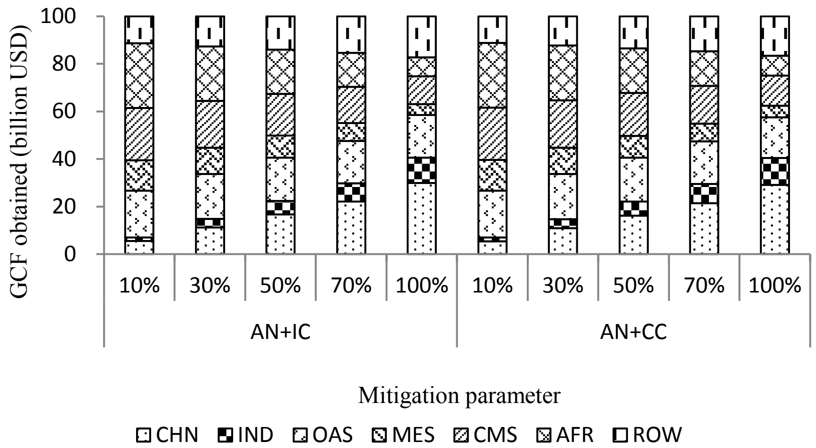

Fig. 7 Regional GCF obtained with different mitigation parameters

The balance of the GCF between mitigation and adaptation may significantly affect the funds obtained by some regions, especially for the emerging economies and least-developed regions. As shown in Figure 7, with an increasing mitigation parameter, different regions usually experience different changing tendencies towards climate funds. Taking AN+IC as an example, with the mitigation parameter increasing from 10% to 100%, the climate funds obtained by CHN increase from USD 6 billion to USD 30 billion, whereas the funds for AFR decrease from USD 27 billion to USD 8 billion. The funds obtained by OAS decrease moderately from USD 20 billion to USD 18 billion.

5. Discussion and Conclusion

The GCF has been one of the core issues in the recent UNFCCC negotiations. This paper focused on the fund-raising and disbursement schemes of the GCF. First, the problem of how the GCF will be raised among the Annex II countries was discussed, and the three approaches of historical emissions responsibility (HR), respective capability (RC) and preference score compromises (PSC) were introduced. Next, we discussed how to allocate the funds among the non-Annex II parties. Regarding the two purposes of the GCF, the adaptation-needs(AN) approach was proposed to achieve the adaptation purpose of the funds, while the carbon reduction contribution (CC) approach and the incremental cost (IC) approach were proposed for the mitigation purpose of the funds. This paper also developed a method to combine abatement efficiency and adaptation fairness of the GCF. Finally, we provided a sensitive analysis.

The analysis in the paper yielded some interesting results. (1) If the GCF is raised based on the PSC approach, the United States and the European Union are the two largest contributors to the funds, sponsoring more than 80% of the GCF. (2)In the case of the AN approach, the African economies with a high level of climate vulnerability get most funds, with a share of almost 30%. (3) The CC approach and the IC approach both encourage the developing countries to reduce their emissions significantly, especially for the emerging economies with high abatement potentials. (4) With an equal split between the AN and CC (or AN and IC) approaches, the amount of USD 100 billion could finance emissions reduction of 1613 $MtCO_2$ (or 2477 $MtCO_2$), while allocating USD 16 (or USD 9) per capita for adaptation in non-Annex II parties.

This paper proposes the PSC approach to share the burden of financing the GCF among the Annex II countries, which improves upon the approaches from previous studies. Many researchers currently believe that contributions from developed countries should be determined based on an agreed-upon formula, which could be designed as a combination of environmental responsibility and economic capacity (Dellink et al. 2009, Müller et al. 2009, Müller 2013, Silverstein 2013). The question is how to balance these two approaches in practice. Assigning weights arbitrarily may be rejected by donor countries because different countries have different preferences. The PSC approach, in which the weights of the alternatives are determined based on voting theory, results in a fair combination between the HR and RC approaches.

The disbursement schemes proposed in this paper have policy implications. Firstly, regarding the climate adaptation purpose, although many scholars argue that adaptation finance should give special attention to the particular needs of the most vulnerable countries(e.g. Kell and Adger 2000, Grasso 2010, Barr et al. 2010, Bird et al. 2011, Ciplet et al. 2013), most of them are qualitative analyses which do not provide an agreed-upon formula. The AN approach, in which the Africa economies could get most adaptation funds, is an improvement on the previous studies as it provides a transparent and simple way for distributing the funds. Although the AN index is likely to be criticized by some developed parties, because it is country specific and currently not all countries have their own national adaptation plans (NAPAs), this approach can be an improvement upon the traditional project based allocation system, which distributes the funds based on the project performance. Regarding the enormous scope of adaptation activities (e.g. scientific research on adaptation activities, publicity campaigns of adaptation knowledge, specific adaptation programs), there are currently no scientific methodologies to evaluate these projects, and the project-based allocation system may cause enormous difficulties in practices. Secondly, regarding the climate mitigation purposes, both the CC approach and the IC approach could finance significant emissions reductions in developing countries, which is particular useful to address climate change globally. In particular, the results indicate that the emerging economies could reduce their emissions significantly. As the emerging economies have already been among the main contributors to global emissions, current mitigation in these countries would lower the atmospheric carbon concentration in the future and decrease climatic losses and risks for poor countries. Therefore, setting aside a part of the funds to encourage the emerging economies to reduce their emissions may be also in line with the long-term interests of the least-developed regions.

However, similar to international negotiations on climate change, designing the GCF is a complex issue involving political, economic, legal and ethical issues, which could evolve into an on-going dialogue. Hence, this research has some limitations. Firstly, the schemes proposed in this paper are to some extent from the perspective of academic research and their political acceptability has not been evaluated. For example, the developed parties may be not in favour of the CC approach as it leaves much mitigation profits, although this phenomenon only occurs in the initial phase and this approach could provide sufficient incentive for developing countries to reduce their emissions immediately. Also, some nations, such as India, could obtain relatively low finance as they experience low abatement potentials. Therefore, some adjustments may be needed when these schemes are put into practice. Secondly, the results presented in the simulation are the initial effects of the GCF design, which lack a long-term assessment of such schemes. Thirdly, to evaluate the effects of the schemes proposed, this paper adopts several well-established methods including the PSC approach (Müller 1999), data from the MIT EPPA model and various MAC estimates, which may results in a bias of the evaluation results. Some of the approaches may benefit from further improvements: for example, the PSC approach for fund-raising could take more dimensions into account than only environmental response-bility and economic capacity, and MACs from other sources could also be adopted to examine the robustness of the results. Additionally, the AN approach is designed based on regional GDP levels and climate damages, and some other indexes, like per capita GDP and a national poverty index, could also be involved. Lastly, regarding the GCF financing, the paper did not take the reduction targets of the Annex II countries into account. Whether there should be a linkage of the reduction targets in Annex II countries and GCF-financing burden may also be an important issue in GCF design (in UNFCCC negotiations, some developed countries may apply for further domestic emission reduction in exchange for a lower GCF finance burden, or vice versa). All of these limitations need to be addressed in the future.

Acknowledgments

The authors appreciate the weekly seminars at CEEP in CAS, from where the earlier draft of the paper got improved. The authors acknowledge the two anonymous reviewers for their valuable comments and suggestions.

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Appendix A: Distribution result sin the AN approach with more detailed results

Table A1 Distribution of GCF among non-Annex II countries in the AN approach (more detailed results)

Country (or region)	Share (%)	Country (or region)	Share (%)	Country (or region)	Share (%)
China	**2.62**	Tunisia	0.70	Argentina	0.58
India	**0.45**	United Arab Emirates	0.64	Barbados	0.75
OAS	**19.95**	Yemen	0.74	Belize	0.76
Bangladesh	1.03	**AFR**	**29.35**	Bolivia	0.76
Bhutan	0.75	Angola	0.70	Brazil	0.00
Brunei Darussalam	0.74	Benin	0.74	Chile	0.66
Cambodia	0.77	Botswana	0.74	Colombia	0.68
Fiji	0.76	Burkina Faso	0.75	Costa Rica	0.74
Indonesia	0.65	Burundi	0.75	Dominica	0.76
Kiribati	0.76	Cameroon	0.73	Dominican Republic	0.75
Lao P.D.R.	0.76	Cape Verde	0.75	Ecuador	0.75
Malaysia	0.59	Central African Republi	0.74	El Salvador	0.80
Maldives	0.75	Chad	0.75	Grenada	0.77
Mongolia	0.81	Eritrea	0.75	Guatemala	0.79
Myanmar	0.86	Ethiopia	0.71	Guyana	0.75
Nepal	0.75	Gabon	0.75	Haiti	0.78
Pakistan	1.04	Ghana	0.72	Honduras	0.89
Papua New Guinea	0.75	Guinea	0.74	Jamaica	0.78
Philippines	0.73	Guinea-Bissau	0.75	Mexcio	0.55
Samoa	0.75	Kenya	0.73	Nicaragua	0.79
Solomon Islands	0.75	Lesotho	0.75	Panama	0.73
Sri Lanka	0.72	Liberia	0.75	Paraguay	0.78
Thailand	1.74	Madagascar	0.76	Peru	0.66
Tonga	0.75	Malawi	0.75	St. Kitts and Nevis	0.75
Vanuatu	0.75	Mali	0.74	St. Lucia	0.75
South korea	0.38	Mauritius	0.75	St. Vincent and the Grenadine	0.75
Singapore	0.62	Mozambique	0.76	Suriname	0.74
Vietnam	1.03	Namibia	0.74	The Bahamas	0.78
MES	**13.88**	Niger	0.75	Trinidad and Tobago	0.73

Algeria	0.65	Nigeria	0.59	Venezuela	0.67
Bahrain	0.73	Republic of Congo	0.74	**ROW**	**10.82**
Djibouti	0.75	Rwanda	0.74	Albania	0.74
Egypt	0.53	Senegal	0.74	Armenia	0.75
Islamic Republic of Iran	0.84	Seychelles	0.75	Azerbaijan	0.72
Iraq	0.66	Sierra Leone	0.74	Bosnia and Herzegovina	0.76
Jordan	0.74	South Africa	0.56	Georgia	0.74
Kuwait	0.68	South Sudan	0.76	Kazakhstan	0.66
Lebanon	0.73	Swaziland	0.75	Kosovo	0.77
Israel	0.66	Tanzania	0.73	Kyrgyz Republic	0.74
Mauritania	0.75	The Gambia	0.75	Latvia	0.75
Morocco	0.70	Togo	0.74	Moldova	0.78
Oman	0.82	Uganda	0.74	Russia	0.16
Qatar	0.68	Zambia	0.74	Tajikistan	0.81
Saudi Arabia	0.43	Zimbabwe	0.75	Turkmenistan	0.73
Sudan	0.73	**CMS**	**22.92**	Uzbekistan	0.71
Libya	0.71	Antigua and Barbuda	0.75	others	1.00

Note：Regional direct losses are from Harmeling and Eckstein (2012); regional per capita GDP is from IMF website

Appendix B: Regional marginal abatement cost (MAC) curves

The MAC curves in this paper are derived from the MIT Emissions Predictions and Policy Analysis (EPPA) model. In particular, Morris et al. (2012)'s regional marginal abatement cost curves for 2020 are adopted here. As stated in other papers, MAC curves can be parameterized by polynomial functions (Böhringer et al. 2005, Anger 2008, Springmann 2013). This research parameterizes EPPA's MAC curves by a polynomial of second degree:

$$C_i(A_i) = a_i A_i + b_i A_i^2 .$$

Where i denotes the aggregated non-Annex II region, A_i is the corresponding emissions reductions, and a_i and b_i are regression coefficients. The regression coefficients a_i and b_i are obtained by an ordinary least squares regression of the MACs on emissions reductions for each region (listed in Table A2). To avoid overestimating, some scale-back factors are considered. More specifically, $C_i(A_i)$ is increased by 3.5% to account for the transaction costs, and this value is inferred from a detailed analysis of clean development projects in non-Annex II countries (Wetzelaer et al. 2007). Moreover, it is assumed that the practical abatement potential is 20% of the total potential to account for short-term abatement potentials in the non-Annex II countries. The corresponding total abatement costs that are needed to reduce emissions by 1 $MtCO_2$ are listed as an illustration for the magnitudes of the regression coefficients.

Table A2 Fit parameters for the parameterization of marginal-abatement-cost curves

	Fit parameters		Goodness of fit	Scaled-back fit parameters	
	a (linear)	b (quadratic)	(R2)	a (linear)	b (quadratic)
China	-1.18E-03	3.12E-06	0.99	1.47E-02	1.24E-04
India	-6.53E-03	3.77E-05	1.00	-3.38E-02	9.75E-04
High Income East Asia	1.23E-02	7.40E-05	0.97	6.37E-02	1.92E-03
Other Asian Countries	-2.80E-02	9.65E-05	0.99	-1.45E-01	2.50E-03

Middle East	3.00E-02	1.31E-04	0.97	1.55E-01	3.40E-03
Indonesia	3.06E-01	-6.30E-04	0.98	1.32E+00	-4.50E-03
Mexico	-5.59E-03	4.82E-04	1.00	-2.89E-02	1.25E-02
Central and South America	-5.59E-03	5.14E-05	1.00	-4.60E-02	1.40E-03
Africa	3.38E-03	5.71E-05	0.99	1.75E-02	1.50E-03
Rest of the World	5.57E-03	1.06E-05	1.00	2.88E-02	2.75E-04

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