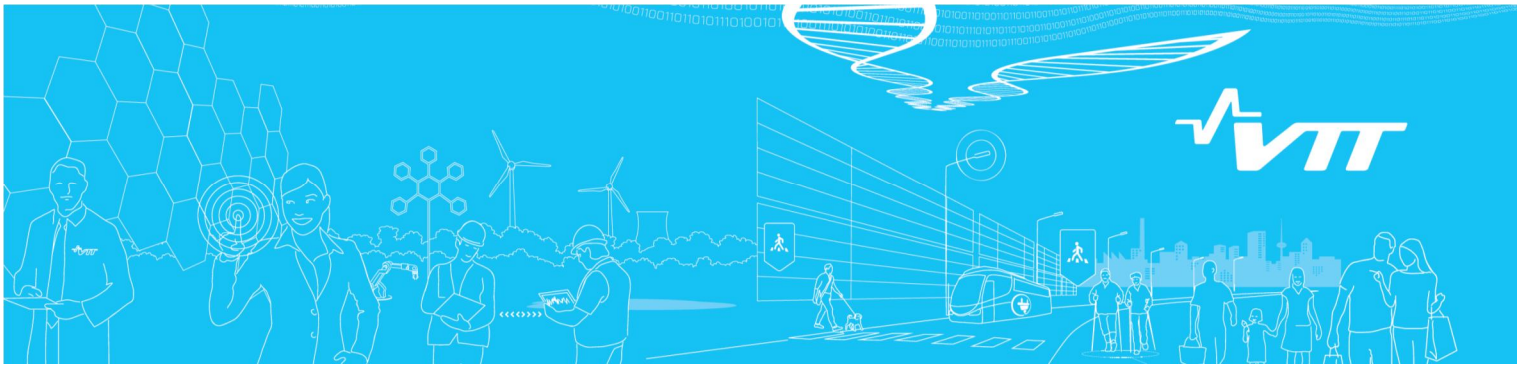

RESEARCH REPORT

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Assessing countries' historical contributions to GHG emissions

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Summary

One of the main principles in the UNFCCC is the recognition of parties' "common but differentiated responsibilities and respective capabilities". Countries' past contributions to climate change or global greenhouse gas (GHG) emissions differ, which has prompted discussion over their historical responsibility for current and future climate change.
This report first assesses the countries' contribution to historical GHG emissions using different scopes of time and emission sources, both as cumulative emissions and cumulatively on per-capita terms. The choice over the scope used affects the countries' contribution significantly. Whether emissions prior to 1990 are accounted affects particularly the contribution of USA, EU and China, whereas the inclusion of LULUCF emissions has a tremendous effect on the contribution of Brazil and Indonesia. When emissions are measured on per-capita terms, the contribution of e.g. Brazil and Indonesia can become significant, while that of EU is decreased considerably. Different assumptions hence lead to very different conclusions on countries' responsibilities for climate change.
The report also analyses the possibility to define per-capita based emission budgets to countries, from which the historical emission would be subtracted. The choice of scope has again large implications for the countries' remaining budgets, but regardless of the choice, such an approach would lead to unrealistic emission pathways for USA and Russia, making it unclear whether such tonne-per-tonne accounting of historical emissions is reasonable in burden sharing. Therefore, to make historical responsibility a usable concept in climate negotiations, the scope of countries' accountability for past emissions should be first settled and efforts should be viewed in a broader context than that of direct emission reductions.

Confidentiality	Public

Espoo 17.8.2015

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Preface

This report analyses the countries' historical contribution to global greenhouse gas emissions, the implications from using historical emissions as a basis for future burden sharing, and the relation between historical contribution and historical responsibility.

The work is a part of a larger research project commissioned by Finnish Ministry of the Environment. The steering group for the project comprised Environment Counsellor Magnus Cederlöf, Counsellor Harri Laurikka and Senior Adviser Paula Perälä. The authors wish to thank the steering group for their insights and helpful comments regarding the report.

The views expressed in this report are those of the authors, and do not necessarily represent the view of Finnish Ministry of the Environment.

Espoo, 17.8.2015

Authors

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1. Background

1.1 The discussion over historical contributions in the UNFCCC

In **1997** Brazil proposed a method to calculate greenhouse gas (GHG) emission reduction targets based on "effective emissions" on a given time period[1]. The method would allocate emission budgets to countries for the time period 1990-2020, based on the increase in global mean surface temperature attributable to the countries' net anthropogenic emissions. As background to the submission, the Brazilian proposal argued that the countries' common-but-differentiated responsibilities could be reflected with their historical contribution to atmospheric GHG concentrations and temperature change. The proposal didn't lead to concrete results, but political and scientific interest remained on the historical contribution of countries to climate change.

Under the UNFCCC, scientific and methodological aspects of the Brasilian proposal were addressed by the Subsidiary Body for Scientific and Technological Advice (SBSTA) at **2001**[2]. In short, the SBSTA concluded that results are sensitive to different assumptions and uncertainties need to be explored better. At **2002**, The SBSTA had a broader and more detailed report on scientific and methodological issues of contributions to climate change[3]. The conclusion was that the effects of greenhouse gases "can be attributed to regional sources". On the other hand, the choice of gases, methods, time period and possible other indicators influence the results quite heavily. The SBSTA agreed that the work should be continued by scientific community.

Subsequent to SBSTA's agreements, Ad Hoc Group on Modelling and Assessment of Contributions to Climate Change (MATCH) was formed. The scientific work of the MATCH was completed at **2007**.[4] The most important results of MATCH were global emission databases from 1850 to 2000 including forestry emissions and a detailed analysis of countries' contribution to climate change.

At **2008**, the SBSTA agreed that the scientific work has provided robust methodologies for quantifying historical responsibilities. The BASIC experts from Brazil, South Africa, India and China published a report on equitable access to sustainable development[5] in **2011**, and a workshop under the same theme was held under the AWG-LCA in Bonn, **2012**[6]. Before concluding this issue, the SBSTA noted that there are uncertainties in the historical emission data[7]. After some years of more silent period on this front, the discussion of historical responsibility has been active from **2013**.

At the Bonn SBSTA session in May 2013, a number of participants called for carbon budget defined on the basis of historical responsibility of emissions[8]. PBL from Netherlands published an improved dataset of countries historical emissions from 1850 to 2010[9]. The data set has also an estimate of the emissions from 2010 to 2030. In SBSTA's 39th session at Warsaw at 2013, Brazil submitted a proposal to include historical responsibility to the 2015 agreement[10].

[1] http://unfccc.int/cop4/resource/docs/1997/agbm/misc01a3.htm
[2] http://unfccc.int/resource/docs/2001/sbsta/inf02.pdf
[3] http://unfccc.int/resource/docs/2002/sbsta/inf14.pdf
[4] http://unfccc.int/files/methods/other_methodological_issues/application/pdf/match_summary_report_.pdf
[5] BASIC experts, 2011: Equitable access to sustainable development: Contribution to the body of scientific knowledge. BASIC expert group: Beijing, Brasilia, Cape Town and Mumbai
[6] http://unfccc.int/meetings/bonn_may_2012/workshop/6658.php
[7] http://unfccc.int/resource/docs/2008/sbsta/eng/06.pdf
[8] http://unfccc.int/resource/docs/2013/adp2/eng/7infsum.pdf
[9] http://www.pbl.nl/en/publications/countries-contributions-to-climate-change
[10] http://unfccc.int/files/na/application/pdf/substa_submission_by_brazil_-_brazilian_proposal_final_corrected.pdf

The aim of the original Brazilian proposal in 1997 was to define a quantitative burden sharing method that could be used to determine the emission ceilings of individual countries. The proposal's calculations were based on the countries' "effective emissions" from the period 1990-2020 – or actually the temperature change associated to the GHG emissions – and the contribution to the atmospheric GHG concentrations by 1990.

The approach taken in the Brazilian proposal is not, however, the only method to turn interpret historical contribution to quantitative emission limits. The proposal also discussed alternative approaches to some extent, but these were dismissed in the proposal. This dismissal was perhaps premature, because the interpretation and implications of historical responsibility remains subjective and contains value judgments[11].

1.2 Objective of the study and some framing questions

In this report, our intention is to clarify the alternatives of how historical contribution could be measured, and illustrate possible implications if historical responsibility would be used in determining emission pathways in the long term.

A number of critical questions exists that frame how the concept of historical responsibility could be considered in the climate negotiations. Three larger questions are:

- *How can historical responsibility be determined?*
- *Can historical responsibility be used to determine future emission targets? If so, how?*
- *What kind of implications would that have for climate negotiations?*

For the first question, it is first necessary to determine the timeframe that countries can be held responsible for their contribution to climate change. Historical contribution doesn't necessarily imply historical responsibility. Can countries be held responsible for actions that took place 100 years back? It is also necessary to determine how reliably the contribution can be estimated. Different emission sources, e.g. fossil CO_2, CO_2 from land use or non-CO_2 emissions, involve very different levels of uncertainty relating to estimated emissions, and the uncertainties increase when emissions further back in history are estimated.

After the appropriate temporal scope and emission source coverage has been determined, it is also necessary to determine how the contribution to climate change is measured, e.g. based on emissions, radiative forcing or temperature change. Although the Brazilian proposal employed an approximation to the countries' contribution to temperature increase, most of the research has focused on estimating countries' cumulative emissions.

Even with the approach of cumulative emissions, it remains unclear how the emissions that occur in different points of time should be compared to each other. For example, is a tonne of CO_2 emitted in 1900 as bad as a tonne of CO_2 emitted in 2000 or in 2100? Emissions occurring at different times contribute differently e.g. towards the 2°C limit, and therefore could treated differently.

This temporal effect is even more pronounced for short-lived gases, such as CH_4, because the temperature response from a tonne of CH_4 is also much more short-lived than the temperature response from a tonne of CO_2, and hence the CH_4 emissions from e.g. 100 years back have only little impact on current and future radiative forcing or temperature increase. Then, the contribution of historical CH_4 emissions, e.g. emitted before 1950, on temperature would be negligible. On the other hand, the long-term temperature response

[11] See e.g. Kallbekken, Sælen & Underdal, 2014: Equity and spectrum of mitigation commitments in the 2015 agreement, TemaNord 2014:519

due CO_2 is directly related to the cumulative level of CO_2 emissions[12]. Based on these, a contribution based solely on cumulative emissions, perhaps excluding non-CO_2 emissions, serves as a transparent and simple approximation.

When moving from countries' historical contribution to historical responsibility, consideration has to be given to what extent a country's contribution can be regarded as responsibility. Countries are heterogeneous e.g. by their size, environmental conditions and economic situation, based on which countries' rights to emit should also differ. Interpretation of such rights affects how much countries have exceeded their allowed limit, or for how large contribution to climate change they should be held accountable.

The final question is then whether and how historical responsibility can be used for the burden sharing of future emission limits. In this context it is necessary to assess whether the burden sharing suggested by a given interpretation of responsibility acceptable from other equity perspectives, such as capability or the ability to pay for the reductions. Does such burden sharing create emission targets that are economically and politically achievable?

[12] Allen, Frame, Huntingford, Jones, Lowe, Meinshausen & Meinshausen, 2009: Warming caused by cumulative carbon emissions towards the trillionth tonne, Nature 458, pp. 1163-1166.

2. Estimates of historical emissions

Historical contribution is often based on estimates of countries' anthropogenic GHG emissions since the preindustrial time. However, estimates that extend for many decades or even a century back are scarce, and have only limited emission source coverage and geographical detail. In addition, the estimates tend to be less reliable the further back to history they extend.

Main features and coverages of existing estimates on historical GHG emissions are summarized in Table 1. The emission inventories submitted to the UNFCCC cover only Annex I countries, and extend only back to 1990. The EDGAR database covers Kyoto emissions from all countries to 1970; and in the EDGAR-HYDE version to 1890, but only as geographically aggregated regions. IEA provides estimates of CO_2 emissions for all countries form 1970. The CDIAC estimates also cover only CO_2, but are reported for all countries and stretch at best back to 1750.

Table 1. An overview of existing estimates on historical GHG emissions.

	UNFCCC	EDGAR 4.2	EDGAR-HYDE	IEA	CDIAC
GHG coverage	Kyoto	Kyoto	Kyoto	fossil CO_2	fossil CO_2
Geographical coverage	Annex I	All countries	Regional	All countries	All countries
Temporal scope	from 1990	from 1970	from 1890	from 1970	from 1750

In addition to these above data sources, the MATCH group has compiled what is perhaps the currently most comprehensive dataset of historical GHG emissions[13]. The dataset covers all sources of Kyoto gases globally starting from 1890, but presented as primarily as aggregated regions, although estimates for the 15 highest emitting countries are included explicitly.

Examples of historical CO_2 emission estimates (excluding land-use emissions) from these data sources are presented in Figure 1 for USA, EU, China and Africa. (Note that the geographical coverage of Europe in EDGAR-HYDE is OECD Europe, and therefore differs from the other datasets.) The figure points out that although the overall trends are similar in all datasets, there exist as large as twofold differences between different data sources for certain regions and years. The largest discrepancy is between the CDIAC and MATCH estimates for Africa, with CDIAC estimating over twice as large cumulative emissions for the time period 1890-2010.

What is important to note here, is that the emissions presented in Figure 1 are the most well-known sources. Despite this, the uncertainties can be considerable. The uncertainties relating to historical non-CO_2 emissions or CO_2 from land-use are likely to be significantly higher.

Further in this report, the countries' historical contribution to climate change is estimated based on the MATCH dataset, due to its widest coverage of different emission sources back to the 19th century.

[13] den Elzen, Olivier, Höhne & Janssens-Maenhout, 2013: Countries' contributions to climate change: effect of accounting for all greenhouse gases, recent trends, basic needs and technological progress, *Climatic Change* 121, pp. 397–412.

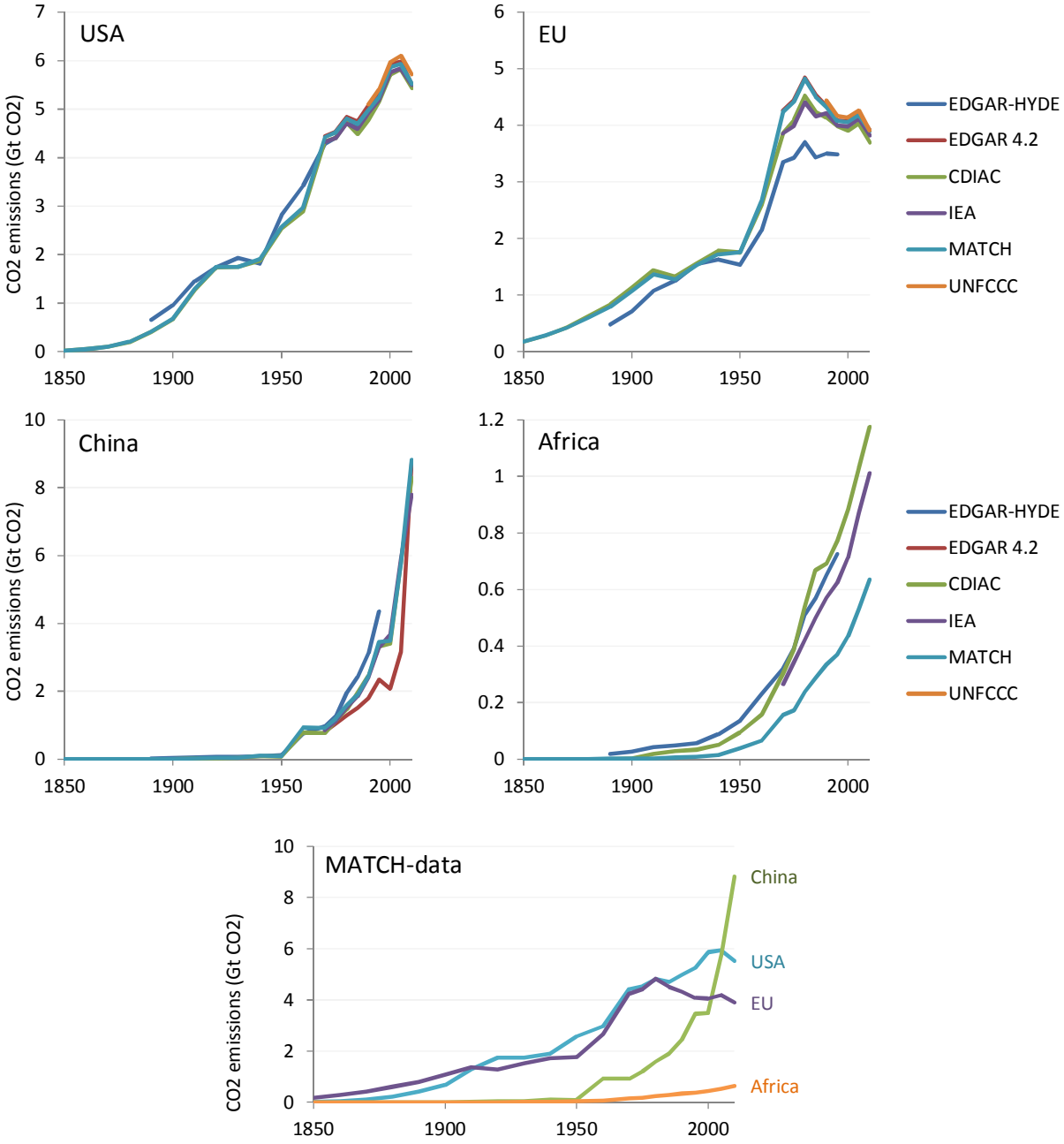

Figure 1. Examples of historical CO_2 emission estimates (excluding land-use) from five data sources for USA, EU, China and Africa. (Note for Europe, EDGAR-HYDE covers only OECD Europe, and hence differs from the EU-28 that is presented by the other datasets). The MATCH data for the four countries or regions are presented at the bottom.

3. Countries' historical contribution to global GHG emissions

In this report, we analyse countries' contribution to climate change, for illustrative purposes, directly based on their cumulative contribution to global GHG emissions. This could be termed as a "tonne-per-tonne" approach, as all emissions are valued with their physical mass in tonnes. Alternative approaches can measure the cumulative radiative forcing or temperature change induced by emissions, or some kind of economic valuation of emissions. Such approaches, however, are more complex and opaque in their calculation; and complicate the interpretation of historical contribution or responsibility.

With the tonne-per-tonne approach, different temporal scopes and coverages of emission sources are however considered. The choice of an appropriate scope is a complex question, and many alternative approaches can be defended from different perspectives. In this report we consider two possible temporal scopes and three coverages of emission sources. Examples of possible rationale for using different approaches are presented below.

Arguments for different temporal scopes:

- From 1990:
  UNFCCC was negotiated in 1992, and countries have made emission inventories that mainly cover emissions only back to 1990. The countries cannot be held responsible for emissions that took place much before the UNFCCC treaty, making future generations accountable for the "sins of their fathers'".
  Uncertainties in historical emissions are much larger than in the estimates for recent years. Making countries' accountable for such uncertain emissions is not justifiable.

- From 1850:
  Greenhouse effect was identified in the mid-19th century, and countries would have had the possibility to acknowledge the problems arising from GHG emissions since that time.
  The countries' total contribution to climate change is independent from whether the emitters have had the knowledge regarding anthropogenic climate change, although this does not imply responsibility for the historical emissions.

Arguments for different emission source coverages:

- Only CO_2 from fossil fuels and cement production:
  CO_2 from fossil fuels and cement production are the largest and most well-known emission sources, for which uncertainty is also the lowest. Taking other emission sources into account would increase the uncertainty in the estimates of countries' contribution to climate change significantly. Making countries' accountable for emissions that are highly uncertain is not justifiable.

- All CO_2, including land-use:
  Land-use and land-use change are significant emission sources or sink for some countries. Particularly deforestation is a large anthropogenic emission source globally, and the majority of deforestation emissions arise from a very limited number of countries. Disregarding this emission category would downplay the historical contribution of these countries.

- All Kyoto gases:
  Emission sources should not be excluded on the basis of uncertainty, but the best available estimates should be used for all emission types and sources. This would lead to the most comprehensive estimate on countries' contribution to climate change.

3.1 Estimates on countries' shares of historical emissions

Countries' shares of historical emissions are presented here using the different temporal scopes and source coverages: either from 1850 or from 1990; and covering only CO_2 without LULUCF, only CO_2 and including LULUCF, or all emissions and sinks of Kyoto gases. The estimates of historical emissions are from the dataset compiled by the MATCH group.

Countries' shares of cumulative global emissions and removals by sinks (hereafter net emissions) are presented in Figure 2. The figure illustrates how the choices regarding the temporal scope and emission source coverage affect strongly how much different countries can be seen to having contributed to global cumulative GHG emissions.

For the USA and EU, the contribution to Kyoto GHG's from 1990 is only half from their contribution to CO_2 from fossil fuels and cement production since 1850. From the latter perspective, USA and EU have emitted over 50% of the considered global emissions, whereas from the latter perspective the contribution is less than 30%. With all source coverages, the contribution of USA and EU to global emissions is considerably higher if emissions before 1990 are taken into account.

However, this picture is reversed for China, whose contribution to global emissions cumulatively from the 1990-2010 period is significantly higher than the contribution from the 1850-2010 period. In fact, the cumulative contribution of China starting from 1990 is higher than that of EU. The same pattern holds also for other emerging economies, but to a lesser extent.

For Africa, Indonesia, other South-East Asia, Brazil and other Latin America, a large difference arises between cases where net emissions from land-use are either excluded or included. The impact is most pronounced for Indonesia, as the contribution to CO_2 emissions including LULUCF is ten times higher than if LULUCF is excluded, irrespective of the temporal scope.

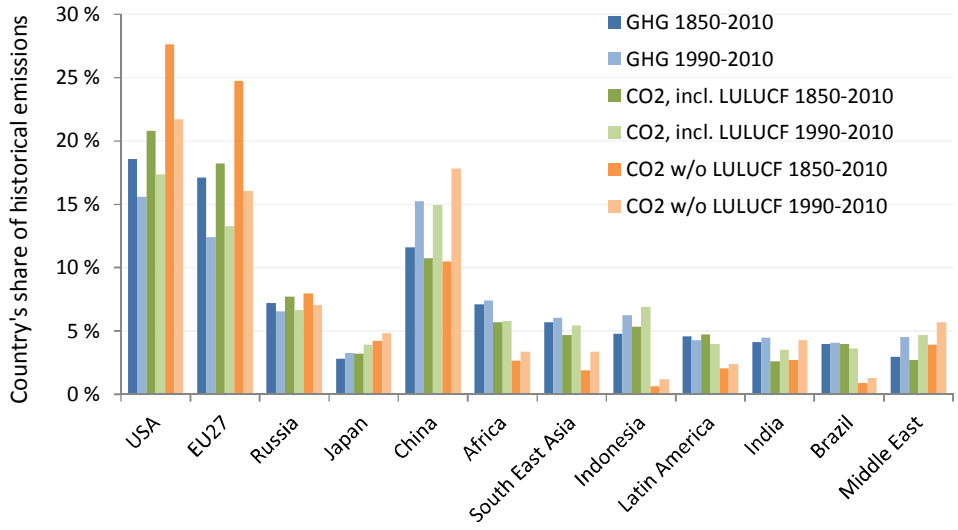

Figure 2. Countries' shares of cumulative historical emissions using different scopes for which emissions and from which time periods are taken into account. Excluding emissions from 1850-1990 reduces the emission contribution of the most developed countries somewhat, and increases especially the contribution of China and Middle East. Excluding LULUCF emissions reduces dramatically the emission contribution of Africa, Indonesia, other South-East Asia, Brazil and other Latin America.

Because different scopes and emission coverages affect individual countries' contribution to cumulative emissions very strongly, countries are likely to have preferences for scope and coverage to be used. Assumed preferences of the countries for the different alternatives considered here are presented in Table 2, by comparing the alternatives to the case of accounting all Kyoto-GHG emissions starting from 1990. Each plus sign denotes a lower contribution of 10%-points than in the reference case. Equivalently, a minus sign denotes 10%-points higher contribution than in the reference case.

Table 2 shows very clearly that especially the inclusion or exclusion of the LULUCF sector affects the countries' contributions with regards to the reference case, and can therefore be a major point of disagreement between countries. Exclusion of LULUCF would benefit all of the presented non-Annex I countries or regions, except India and Middle-East. The majority of non-Annex I countries would also benefit from the inclusion of emissions from the 1850-1990 period, although the impact depends on the coverage of emission sources.

Table 2. The difference in a county's share to historical emissions with different scopes, when compared to a reference case of considering Kyoto-GHG's emissions from 1990-2010. Each plus sign denotes a 10% lower contribution than in the reference case, and a minus sign denotes a 10% higher contribution. The plus and minus signs therefore mark respectively the country's assumed preference or dispreference on that given scope for assessing its contributions to historical emissions.

GHG coverage:	GHG		CO2, incl. LULUCF		CO2 w/o LULUCF	
Temporal scope:	1850-2010	1990-2010	1850-2010	1990-2010	1850-2010	1990-2010
USA	-	reference case	---	-	-------	---
EU27	---		----		---------	--
Russia			-		--	
Japan	+			-	---	----
China	++		++		+++	-
Africa			++	++	++++++	+++++
South East Asia			++		++++++	++++
Indonesia	++		+	-	++++++++	++++++++
Latin America			-		+++++	++++
India			++++	++	+++	
Brazil				+	+++++++	++++++
Middle East	+++		++++		+	--

3.2 Cumulative contribution on per-capita basis

The historical contribution depends strongly on the size of the country, as could be seen from Figure 2. The larger the country, the larger the emissions usually are, leading inherently to larger contribution to global cumulative emissions and climate change. A country of a large size can be thought to have the *right* for greater emissions. Conversely, the responsibility of a larger country should be perceived to be lower than the responsibility of a smaller country with an equal amount of emissions. This reasoning requires that the contribution needs to be equalized to reflect the size of countries in some way, and the size can be measured in different ways. In this report, we take an egalitarian view and measure the countries' size as their population, and hence the contribution to cumulative emissions need be considered on per-capita terms. Alternatively, one can size the countries from an economic viewpoint based on their economic output, leading to a GHG/GDP metric by which countries would be compared; and other measures can be also devised.

Figure 3 presents the countries' contribution on cumulative-per-capita basis, dividing the cumulative emission with the cumulative population from the particular timeframe in question. On per-capita terms, the contribution of the EU and China is not as significant as in Figure 2, whereas the contribution of Russia, Japan are increased somewhat. China's cumulative- per-capita GHG emissions, however, are twice as large during 1990-2010 period than in the 1850-2010 period, and are estimated to be 8.5 tCO_2/capita in 2010.

If LULUCF is included, the contribution of Indonesia, Brazil Latin America becomes significant, and with some source coverages exceeds that of EU. As a concrete example, the cumulative per-capita GHG emissions from 1850-2010 of Brazil are slightly over 10 t/capita, whereas it is only 8 t/capita for EU. For Indonesia, the per-capita contribution from LULUCF has been high particularly after 1990, and the cumulative-per-capita emissions for all GHG's from 1990-2010 are estimated to be around 13 tCO_2/capita.

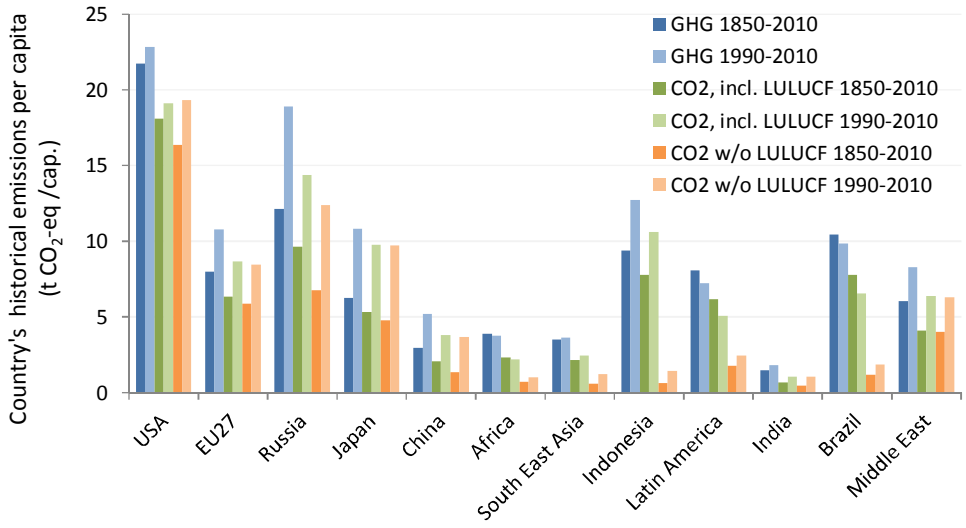

Figure 3. Countries' shares of historical emissions on cumulative-per-capita basis, using different scopes for which emissions and from which time periods are taken into account.

3.3 Finnish GHG emissions from 1860 to 2010

The MATCH dataset used above is only available for major countries and aggregate geographic regions. Currently there are no datasets that would present country-level estimates for all Kyoto GHG's back to 19th century.

Estimates of Finland's historical CO_2 emissions from fossil fuels and cement production back to 1860 are available from CDIAC and Statistics Finland, and for non-CO2 emissions back to 1970 from EDGAR. The CDIAC and EDGAR databases or the estimates from Statistics Finland do not, however, cover the CO_2 emissions and sinks from the LULUCF sector.

The emissions and sinks in the LULUCF sector reflect the changes of carbon stock in living tree biomass, litter and soil. Liski et al. (2006) have estimated the accumulation of carbon in Finland's forests between 1922 and 2004 based on the data from National Forest Inventories[14], and these stock-change estimates were converted to CO_2 to provide numbers comparable to the LULUCF inventory.

In addition, because the estimates in Liski et al. (2006) extend only to 2004 and exclude data from the two most recent forest inventories, estimates on the carbon stock changes in living trees were calculated in this study to provide more recent estimates, and allow better comparison to net LULUCF emission in recent years. However, it is important to note that this estimate has more limited coverage of carbon pools than in Liski et al. (2006) and in the LULUCF emission category, and cover only the largest carbon pool, i.e. that of living tree biomass.

These estimates of historical forest land sinks are presented in Figure 4. Before the 1970's, the cumulative sink has been close to zero, apart from the large sink around the Winter War and Continuation War (1939-1945). After 1973, the sink has been of considerable magnitude.

[14] Liski, Lehtonen, Palosuo, Peltoniemi, Eggers, Muukkonen & Mäkipää, 2006: Carbon accumulation in Finland's forests 1922-2004 - an estimate obtained by combination of forest inventory data with modelling of biomass, litter and soil, Ann. For. Sci. 63, pp. 687–697.

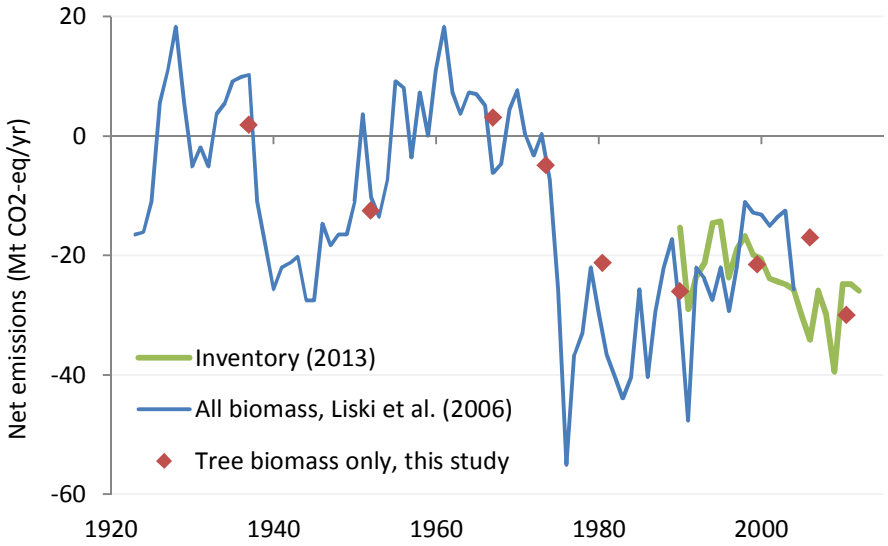

Figure 4. Estimates on the net emissions (emissions minus sinks) from the LULUCF sector in Finland.

The estimates of total historical emissions and sinks are presented in Figure 5, along with Finnish population, from 1860. Finnish CO_2 emissions rose rapidly during industrialization after 1950, reaching more moderate rate of increase after 1970, and have been in a fluctuating decline since 2003. Due to the large sink during the 1940's, the cumulative emissions including forest sinks are negative based on the available data. After 1970, the cumulative sink has been roughly one third of the cumulative GHG emissions.

Population, however, has been on increasing steadily since 1850. The relation between these developments implies that per-capita emissions in Finland were very low prior to 1950, and hence if the Finnish contribution to global emissions per-capita is lower with a timeframe extending to times before 1950. In fact, the fossil CO_2 emissions per capita have been less than 2 tCO_2/capita before 1954. After this, fossil CO_2 emissions rose rapidly to over 10 tCO_2/capita in the following 20 years, but have declined to 9.3 tCO_2/capita in 2012. However, the role of forestry sinks is significant for Finland, and the per-capita emissions in 2012 are only 4.6 tCO_2/capita for CO_2 including LULUCF, and 6.5 tCO_2-eq/capita for all Kyoto GHG's.

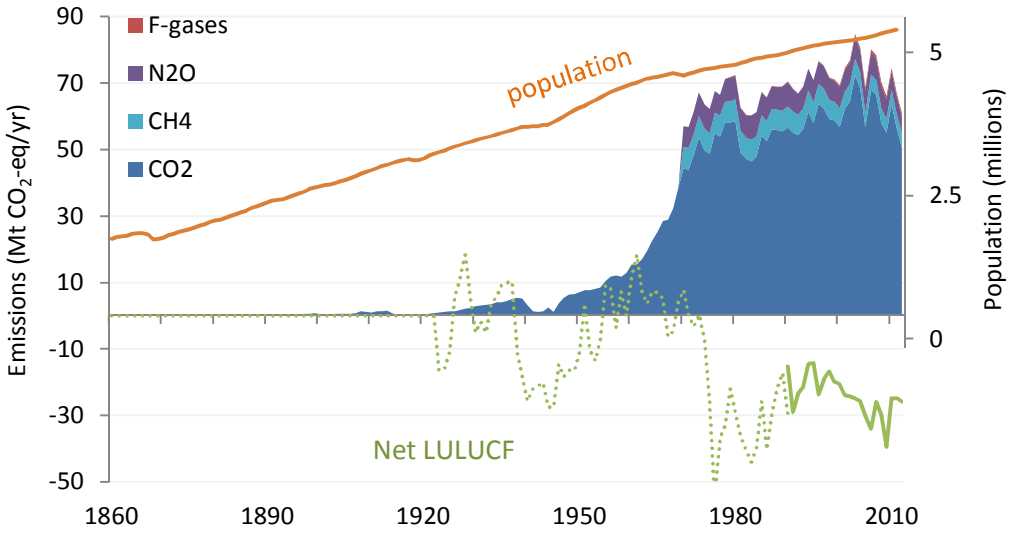

Figure 5. The development of Finnish Kyoto-GHG emissions and population. Estimates for fossil and cement CO_2 and start from 1860, for other Kyoto gases from 1970. Population is presented in millions on the right axis, also from 1860. The net emissions from the LULUCF sector are from Liski et al. (2006) for the period 1923-1990, though covering only forest carbon stocks (dashed line); and from 1990 the values reported to the UNFCCC (solid line).

Finnish historical emissions on cumulative-per-capita basis are presented in Table 3 for those scopes for which data is available. By comparison to the average per-capita emissions in the EU, the Finnish contribution per-capita is less than the EU average with all assessed scopes, except with CO_2 excluding LULUCF and starting from 1990.

Table 3. Finnish historical emissions on cumulative-per-capita basis, using different scopes for which emissions and from which time periods are taken into account.

GHG coverage:	GHG		CO2, incl. LULUCF		CO2 w/o LULUCF	
Temporal scope:	1850-2010	1990-2010	1850-2010	1990-2010	1850-2010	1990-2010
Finland	n/a	9.4	2.9	7.1	5.2	11.7
EU average	8.0	10.8	6.3	8.7	5.9	8.5

4. Burden sharing based on historical contribution

What implications historical contribution could have for the burden sharing of future emissions? Here, we take the 2°C target as the overall mitigation objective for the UNFCCC. It has been presented that the peak temperature increase is insensitive to the shape of emission pathways, but is robustly proportional to the amount of cumulative emissions since the preindustrial period[15]. Based on this, the 2°C target is closely related to a carbon budget – a target that would limit cumulative CO_2 since the preindustrial period to approximately 3700 Gt of CO_2. Currently, slightly more than half of this budget has already been used. As the 2°C target requires in the long-term that emissions have to be near-zero by the end of the century, it can be assumed that the emission budget will be used up by 2100.

The burden sharing of countries' mitigation efforts requires that this global carbon budget is split to country-level budgets. Following the approach earlier in this report, the emissions budgets are allocated to countries on a cumulative per-capita basis, for either Kyoto GHG's, CO_2 or CO_2 excluding LULUCF; and either for the time period 1850-2100 or 1990-2100. If historical contribution is taken into account only from 1990, the emissions prior to 1990 are first subtracted from the global budget, and after that the remaining budget is shared on cumulative per-capita terms for the countries. This burden sharing would result in that the cumulative per-capita emissions would be equal across all countries, assuming that all countries use up their budget by 2100.

The cumulative per-capita burden sharing requires a country-level population scenario up to the year 2100. For this purpose, the IIASA SSP2 population scenario is employed. The scenario assumes a moderate increase in global population that peaks at 9.4 bn. around 2070 and then contracts back to 9.0 bn. by 2100. In this scenario, population growth slows down by 2050 in all regions except Africa, where the population is assumed to grow for the whole decade.

The emission budgets based on this cumulative per-capita burden sharing are presented in Figure 6 for selected countries. The figure presents the total budget, which is proportional to the cumulative population of the country or region during the time period 1850-2100 or 1990-2100; and the share of the budget that has been used already in the associated timeframe. In cases where the country has already used up its whole budget up to 2100, the difference is shown as "emission debt" to the budget.

If emissions are accounted from 1850, USA and Russia have notable emission debts. EU has either a small remaining budget or a small debt, depending on the emission coverage. If historical contribution is considered instead from 1990 onwards, USA and Russia have only small emission budgets left while EU has between 42% and 52% of its budget left, depending again on the coverage of emission sources.

The developing countries, on the other hand, have very large emission budgets left in all considered cases– excluding Brazil. The remaining budget is particularly large for India and South-East Asia. Although the budget of China seems large, it would suffice only for 30-50 years if Chinese emission would remain at the 2010 emission level. Given that China's emissions have been rising rapidly, the budget would in reality suffice for much shorter timeframe unless the Chinese emission pathway is rapidly steered into a steep decline.

For Brazil, the remaining budget is large only if LULUCF emissions are excluded. If they *are* included and emissions are accounted from the 1850-1990 period, the remaining emission budget is small for Brazil – only 18-19 times the 2010 emission level, meaning that Brazil would use up its whole emission budget in a couple of decades.

[15] Allen, Frame, Huntingford, Jones, Lowe, Meinshausen & Meinshausen, 2009: Warming caused by cumulative carbon emissions towards the trillionth tonne, Nature 458, pp. 1163-1166.

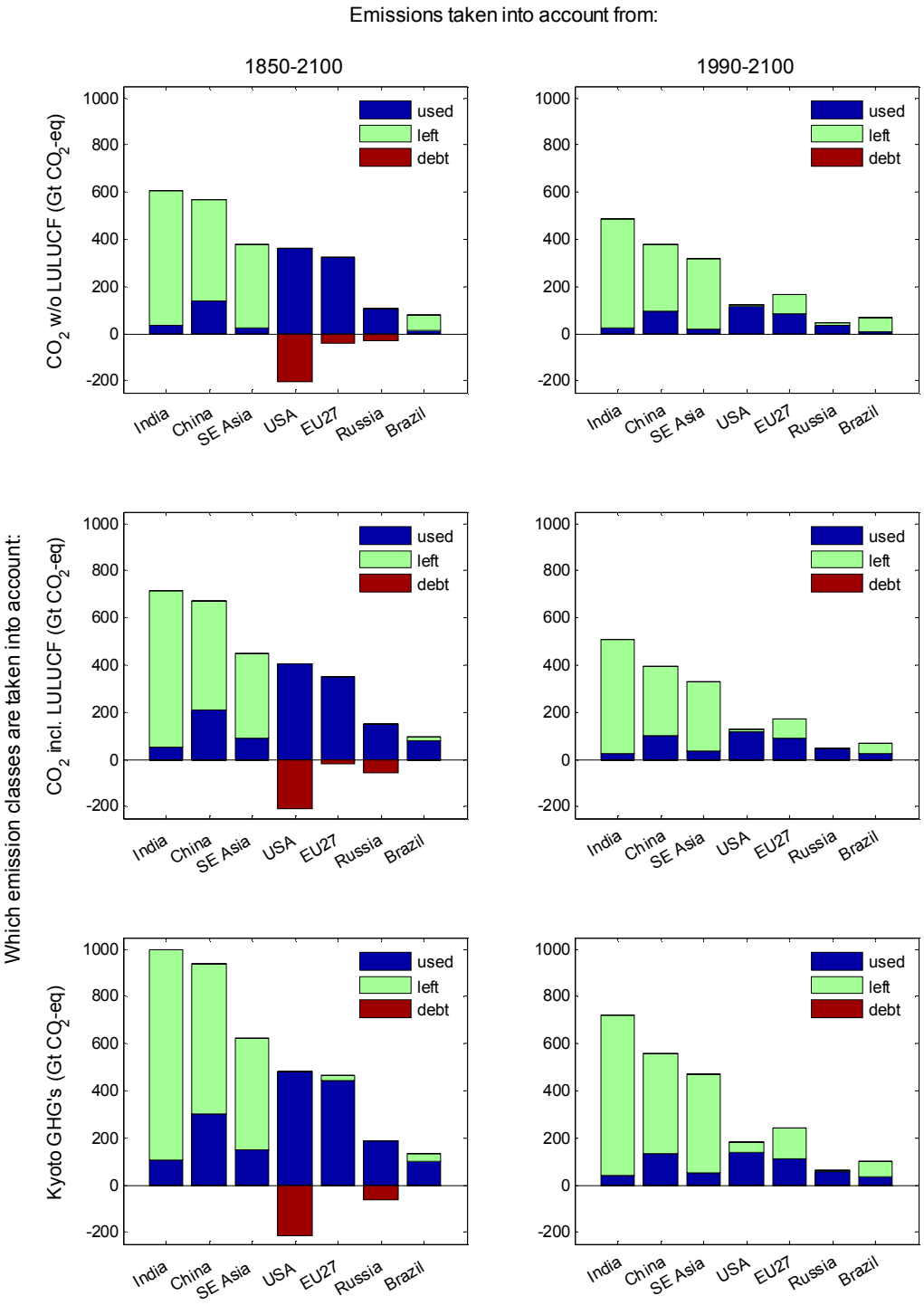

Figure 6. Global emission budget up to 2100 shared between countries on per-capita basis, for different temporal scopes (1850-2100 on the left, 1990-2100 on the right) and coverage of emissions sources (CO_2 without LULUCF, CO_2 or Kyoto-GHG's; respectively on top, center and bottom rows). The columns are split between the emission budget that has been used already and the part that is still left after 2010. If the historical emissions from the timeframe in question are larger than the country's budget, the difference between these is marked as 'emission debt'.

Based on the emission budgets presented in Figure 6, stylized emission pathways were calculated to better illustrate the outcomes of such burden sharing, and what would be needed from the countries to meet these emission budgets. The emission pathways are presented in Figure 7.

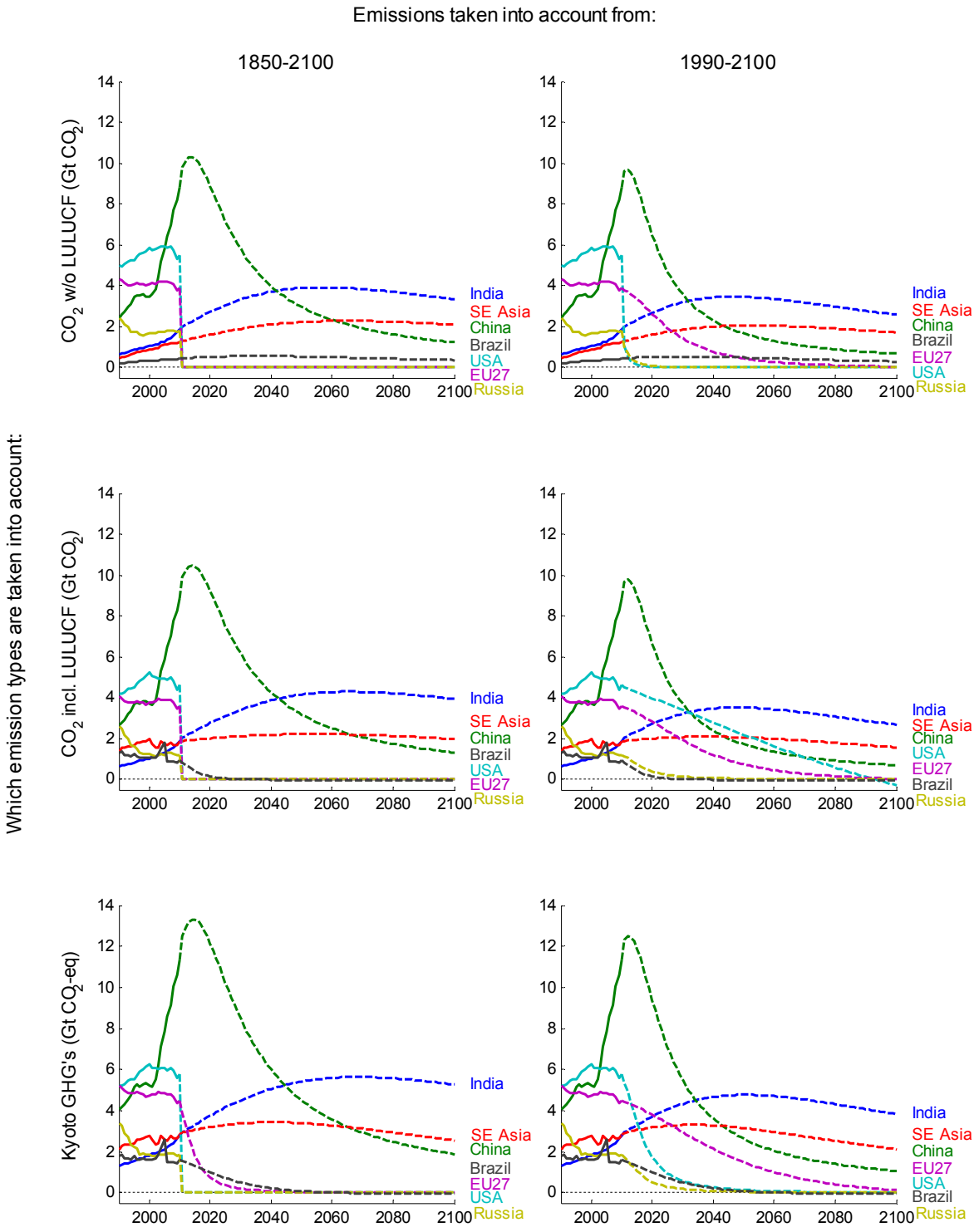

Figure 7. Emission pathways for different countries, calculated by sharing a global emission compatible with the 2°C target on per-capita basis. Solid lines indicate historical emissions and dashed lines are future emission pathways. Most accounting options would require Annex I countries to achieve zero-emissions almost immediately. China would have to get its emissions into a rapid decline between 2015 and 2020. Brazil would have to achieve zero-emissions between 2030 and 2060, unless LULUCF emissions are excluded. India's emission would peak between 2040 and 2060.

In cases where a country has used up all its emission budget (has emission debt in Figure 6), it would be forced to achieve zero-emissions immediately. This is obviously impossible in reality, and renders such burden sharing infeasible. This rules out the cases where contribution per-capita is calculated starting from 1850.

If the contributions per-capita are instead accounted from 1990, USA and Russia would have to achieve zero-emissions somewhere between 2015 and 2040. Also this seems highly unrealistic at best, or outright impossible at worst.

The emission pathways for EU, however, resemble very much the low-carbon roadmap of EU, as these emission pathways involve reductions between 80% and 90% at 2050, when compared to 1990 levels. Therefore it can be concluded that the EU roadmap would be compatible with a cumulative per-capita based burden sharing that takes historical emissions starting from 1990 into account.

The analysed burden sharing would have mixed impacts for the non-Annex I countries. The emissions in China have been rising extremely rapidly since 2000, and despite its large population, the cumulative per-capita burden sharing would require that China turns its emissions into a rapid decline between 2015 and 2020 in all considered cases. This change in the emission pathway –required for meeting the cumulative per-capita emission budget – is much more rapid than the current plans of China to achieve a declining emission path in 2030 at the latest, and would be extremely challenging to achieve in practice.

Brazil would have to achieve zero-emissions between 2030 and 2060, unless LULUCF emissions are excluded. If LULUCF is excluded, Brazil would be allowed a moderate increase in its emissions up to 2100.

India – and also South-East Asia in most cases – would be allowed to increase its emissions for the whole century. Also in this case, the burden sharing on cumulative contribution per-capita bases would produce impacts that might be unrealistic, or unfair from other perspectives of equity. If India would not need to reduce its emissions, but other countries with e.g. similar welfare or abilities would have, this would violate horizontal and vertical equity principles.

5. Conclusions for advancing global climate policy

Historical responsibility is an appealing concept in the climate negotiations. This philosophical appeal does not, however, ensure that it would be applicable in practice – e.g. as a basis for burden sharing of future emissions – if the concept is too ambiguous, if it conflicts with other equity principles, or if the outcomes from following this approach are unattainable in reality. There is no single interpretation for what historical responsibility means. Should historical responsibility be put in practice in some way, judgement would have to be made on to how far back in history countries can be held accountable for their emissions. Such an arrangement would keep countries liable for something they did not realize at the time, and do not have control over anymore.

Past quantitative research on the topic has tended to sidestep the question of responsibility – which is more philosophical than practical – and instead evaluated countries' historical contribution to climate change. However, also the definition of contribution is open for interpretation, e.g. whether it refers to the contribution to global GHG emissions, radiative forcing, or temperature increase.

As long as there is no solid interpretation of what responsibility and contribution mean in detail, parties are likely support an interpretation that is favourable to themselves. This can hinder or even prevent the widespread use of these concepts in practice. Further, focusing on concepts that are vague or open to interpretation can slow down the negotiation process.

The most direct and transparent interpretation of contribution was used in this report – i.e. that of calculating the cumulative historical emissions tonne-per-tonne. Even with this simple approach, the historical contribution of countries can be calculated for different timeframes and coverages of emission sources; and each of these choices can be justified by considerations of accountability, existence of emission estimates, or the reliability of these estimates. Yet, these choices of scope affect very strongly how much some given country has contributed to cumulative global emissions.

For some countries using different scopes for the applied timeframe and emission sources, the cumulative emissions can differ by a factor of ten. This large difference arose solely from the decision of whether LULUCF emissions are taken into account or not. The proposal for historical contribution came initially from Brazil; but if land-use emissions are taken into account, the historical contribution per-capita of Brazil is approximately the same as that of EU. With full accounting of all anthropogenic emissions – including land-use – the historical responsibility framework could be very unfavourable for Brazil.

Moreover, a direct comparison between countries' contributions is not meaningful, because countries vary by their sizes. A large country has perhaps inherently contributed more towards global emissions than a small country. Therefore the contributions have to be scaled somehow to reflect the size of countries. Although the size of population is perhaps the least contested measure of country's size – one that leads to the comparison of per-capita emissions – it is not the only measure. This measure of size is another potential source of disagreement, with some countries favouring equalization of emissions on per-capita terms, other e.g. on per-GDP terms.

A definitive test of applicability for historical responsibility is whether it can be used to define burden sharing that could be implemented in practice, when e.g. the countries' capabilities and ability-to-pay for carrying out the necessary emission reductions are taken also into account. However, when a global emission budget compatible with the 2°C target was split to country-level budgets based on their cumulative per-capita emission up to 2100, the result was far from feasible. If emissions were accounted from 1850, USA, EU and Russia had already used their whole emission budget, and therefore cannot feasibly meet their implied emission budgets. When accounting only from 1990, USA and Russia would have to reach

zero-emissions well before 2040. Both of these outcomes are unrealistic, rendering such burden sharing infeasible.

However, this infeasibility does not mean that these countries should be completely absolved from their historical responsibility, but merely that these countries are in practice unable to meet their responsibility in full, in the context that was assumed here. How this inability should perceived remains an open question.

For the EU, burden sharing based on cumulative per-capita emissions from 1990 would lead to EU emission pathways that are very close to the EU low-carbon roadmap. This is an interesting outcome, because the general view has perhaps been that burden sharing based on per-capita emissions or historical responsibility are disadvantageous for Annex I countries. In this case, however, both of these approaches were used simultaneously – though the historical contribution reached only back to 1990 – and the outcome was still compatible with the own plans of the EU.

These calculation experiments highlight the critical question in the historical responsibility context: from how long back countries can be considered responsible for their emissions? The most critical topic in current climate negotiations is – to which the historical responsibility concept also links directly to – what kind of commitments countries should be willing to take. However, if future commitments would be determined directly by countries' historical emissions, this would make countries responsible for past actions, for years for which no commitments have been determined.

Therefore, using historical responsibility directly as a basis for future burden sharing would be equivalent to making past years compliance years for countries' future emission reduction commitments. Agreeing on future emission reductions has been extremely difficult, and it is likely to be equally difficult to agree on the responsibility for historical emissions – or reductions that should have, but did not take place – in retrospect.

One of the main principles in the UNFCCC is that the protection of climate system is based on the "common but differentiated responsibilities and respective capabilities" of parties. This principle is a balance of two components: responsibility and capability. The burden sharing approach employed in this report takes a very strict interpretation of responsibility – that countries are held accountable for all of their historical emissions, tonne-per-tonne. Such an approach, however, can lead to future commitments that are beyond the capabilities of developed countries, hence violating the capability principle of UNFCCC Article 3.1.

The burden sharing presented here is nevertheless a somewhat theoretical exercise, as top-down burden sharing seems not to play an important role in the climate negotiations, which at least currently focus on a pledge-and-review approach. In addition, it is important to note the limited scope of effort that was captured in the analysis above, as the burden sharing did not include the countries contributions to providing climate financing or developing technologies for climate mitigation and adaptation. Hence, the question over countries' responsibility and appropriate level of effort cannot be answered solely through the straightforward tonne-per-tonne calculation of historical and future emissions. Nevertheless, it provides some guidance for countries' future emission commitments from one perspective that should be complemented with considerations from other perspectives.

In order to use historical responsibility in the climate negotiations, the scope of countries' accountability for past emissions should be first settled, clearing the ambiguity related to the concept of responsibility. Without this, different parties can draw upon a suitable interpretation to promote their individual positions, possibly entrenching and aggravating the disagreement between parties. Insistence on a unilaterally chosen interpretation of responsibility by a number of parties might prolong the impasse of climate negotiations, particularly if the implications of such interpretation conflict with the "respective capabilities" part of Article 3.1.

Further, the context of the UNFCCC climate negotiations is broader than the parties' emission levels and future emission reduction targets. Technology development and transfer, financing of mitigation and adaptation, and capacity building of developing countries are all efforts from developed countries to fulfil their responsibility, alongside with taking the lead in emission reductions. Comparing these different kinds of efforts is obviously difficult. This notwithstanding, a tight focus on the responsibility for historical emissions misses the broader context of the negotiations.