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Baseline projections for Latin America: base-year assumptions, key drivers and greenhouse emissions

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ABSTRACT

This paper provides an overview of the base-year assumptions and baseline projections for the set of models participating in the LAMP and CLIMACAP projects. We present the range in baseline projections for Latin America, and identify key differences between model projections including how these projections compare to historic trends. We find relatively large differences across models in base year assumptions related to population, GDP, energy and CO_2 emissions due to the use of different data sources, but also conclude that this does not influence the range of projections. We find that population and GDP projections across models span a broad range, comparable to the range represented by the set of Shared Socioeconomic Pathways (SSPs). Kaya-factor decomposition indicates that the set of baseline scenarios mirrors trends experienced over the past decades. Emissions in Latin America are projected to rise as a result of GDP and population growth and a minor shift in the energy mix toward fossil fuels. Most scenarios assume a somewhat higher GDP growth than historically observed and continued decline of population growth. Minor changes in energy intensity or energy mix are projected over the next few decades.

1. Introduction

Since 1880, global mean temperatures have risen by approximately 0.85 °C; another 0.3 °C to 4.8 °C is likely to occur by the end of the coming century (IPCC, 2013). Limiting temperature rise to the lower end of this range will require substantial mitigation effort. Integrated assessment models (IAMs) are often used to support decisions on mitigation policy by developing scenarios that depict possible trends in energy production and emissions, both in the absence of climate policies (i.e. "baseline" scenarios) and in the presence of climate policies (i.e., "policy" scenarios). Baseline scenarios provide useful information for assessing why policies are needed and what the potential cost of policy intervention will be. Key inputs to these baseline scenarios are projections of driving forces such as population, economic activity, and assumptions on technology change, which can differ significantly across models. As a result, key model outputs from baseline scenarios, including projections of energy use and emissions over time in the absence of climate policy can differ significantly as well.

The purpose of this paper is to provide background information on model baseline assumptions and projections which will allow us to

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explain differences in model results explored in subsequent papers in this special issue. More information on the model comparison project described in this special issue can be found in van der Zwaan et al. (2015). Specifically, we provide an overview of core baseline projections for countries in the Latin American region. Previous work has assessed baseline scenarios in Asia (Blanford et al., 2012) and Africa (Calvin et al., 2013). We follow a similar methodology to those studies and use the results from a set of models participating in a recent model intercomparison exercise: the CLIMACAP-LAMP project.[2] As part of our study, we present the range in core baseline projections for Latin America across participating models, identify key differences between model projections, and compare these projections to historic trends. Finally, we compare base-year data sources used to parameterize the models in order to better understand base-year differences across the models. Additional information on the scenarios and models included in this study is available in subsequent papers in this special issue—i.e., van der Zwaan et al. (in this issue) on technology transformation; Calvin et al. (2016–in this issue) on agriculture and land use; and Clarke et al. (2016–in this issue) on the response to climate policy.

The geographic focus of this study is the Latin American regions that are most widely represented in the set of participating models: Brazil, Mexico, the full region of Latin America (including the Caribbean), and the world. A smaller set of models also provides results for Argentina, Colombia and Chile which can be found in the Electronic Supplementary Material (ESM). We refer the reader to other studies in this special issue for more detailed information on Argentina (Di Sbriovacca et al., 2016–in this issue), Brazil (Lucena et al., 2016–in this issue), Colombia (Calderon et al., 2016–in this issue), and Mexico (Veysey et al., 2016–in this issue). This study covers the period of 2005–2050, with results for the longer term (up to 2100) provided in the ESM. The models participating in the CLIMACAP-LAMP project are ADAGE (Beach et al., 2011), EPPA (Paltsev et al., 2005; Paltsev et al., 2014), GCAM (Wise et al., 2014), IMAGE (Stehfest et al., 2014; van Vuuren et al., 2007), iPETS (O'Neill et al., 2012), LEAP-UNAM, MEG4C (Alvarez et al., 2014; DNP et al., 2014; MLED, 2013; World Bank and DNP, 2015), MESSAGE-Brazil (Nogueira et al., 2014), Phoenix (Daenzer et al., 2014), POLES (Criqui et al., 2015; Griffin et al., 2014; Kitous et al., 2010; Markandya et al., 2014), TIAM-ECN (Kober et al., 2014; Van Der Zwaan et al., 2013) and TIAM-WORLD (Kanudia et al., 2014; Labriet et al., 2013).

The paper is organized as follows. Section 2 discusses the base-year data and model assumptions. Section 3 presents the model core baseline projections for the participating models and compares these projections to historical trends. In Section 4 we provide results from a Kaya-factor decomposition analysis to identify the key factors driving changes in emissions and variation across models. Finally, Section 5 provides a closer examination of historic trends in Latin America and how these trends compare to the core baseline scenario projections.

2. The starting point: base-year data

A number of sources exist for historical data on population, GDP, energy use and emissions. It is common for these variables to differ across data sources. While the models partly use the same data sources (see Table 1), still differences exist, which contributes to differences in the base-year as presented in Section 2.2. Furthermore, models use different base years, so that differences may exist even if the same data sources are used. Finally, data is regularly updated. We focus our comparison of base-year data on the year 2005, as this is the most commonly adopted base year (i.e., eleven out of thirteen models participating in the CLIMACAP-LAMP project). The goal of this section is to highlight the differences in estimates across external datasets as it helps to explain why there are differences in the reported base year data for the CLIMACAP-LAMP models. Given the larger scope of this paper, we do not attempt to explain why these differences exist in the published data. Section 2.1 reviews the data (published by a number of sources) used to parameterize the models, and Section 2.2 examines the variance in base-year estimates submitted to the CLIMACAP-LAMP scenarios database.

2.1. Variation across historical databases

Fig. 1 compares 2005 base year variables across data sources, many of which are used by the models participating in the CLIMACAP-LAMP project.[3] The figure shows deviations in 2005 values for GDP, CO_2 emissions, population, and primary energy use from different data sources relative to one source, often the source most commonly used by the models. In some cases (e.g., GDP), values are compared across a number of unique data sources. In other cases, values are also compared across different versions of a single source. In the figure, values for 2005 are provided for each of the individual CLIMACAP-LAMP regions (Argentina, Brazil, Chile, Colombia, and Mexico) as well as for the aggregate Latin American region (LAM) which includes the Caribbean, and Central and South America.

As shown in Fig. 1, the lowest variation across data sources is found with GDP. It is less than 1% for the reported countries and sources. The widest range of variation across data sources exists in the case of the aggregate LAM region. The value of GDP from the World Bank and the UN match, but the IMF and IEA GDP estimates are approximately 4–5% lower.

The spread in population data is similar to the spread observed for GDP. In the case of Brazil and Columbia, the data for population are mostly in agreement. Population estimates for Mexico are similar across all data sources except for the 2013 UN revision (the data source of reference) which is 4–5% higher. This increase in the estimation for Mexico's population goes back to 2050 in the 2013 UN report and coincides with higher estimates for crude birth rate during that same 55-year period. In the case of LAM, the three data sources are consistently lower than the reference data source, with a range of estimates of 1–5%.

The 2007 IEA primary energy estimates are within ±5% of the 2013 data, but there is no consistent story across regions. The 2007 estimates for Argentina, Brazil, and LAM are lower than current estimates, while they are higher for Chile, Colombia, and Mexico. This partly explains why also models may produce different base year estimates while using data published by a single agency.

The reference data for CO_2 emissions from the CDIAC include emissions from natural gas flaring and cement production while the three comparison sources do not. As a result, reference source emissions are higher in all regions. Aside from this, there are no discernable patterns in the data. For LAM, Argentina, Chile, and Mexico, the CDIAC emissions estimate without flaring and cement is higher than the IEA estimate, but for Colombia, these emission estimates are lower than the IEA emission estimates by a few points. In the case of Brazil, the CDIAC emission estimates without flaring and cement matches the current IEA estimates. There are notable differences between the two versions of the IEA data: the current version shows higher emissions from LAM and Argentina, but lower emissions for Brazil, Chile, Colombia, and Mexico.

2.2. Variation across models

Across the four key reporting variables – GDP, population, primary energy, and CO_2 emissions from fossil fuel combustion and industrial

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[2] The Integrated Climate Modelling and Capacity Building Project in Latin America (CLIMACAP) is a European Commission funded effort focused on analyzing the effects of mitigation strategies in key Latin American countries. The Latin American Modeling Project (LAMP) is a similar effort funded by the U.S. Environmental Protection Agency and the U.S. Agency for International Development. Coordinated effort between these two projects has allowed for the development of a multi-model comparison project focused on mitigation in Latin America. More information on the two projects is available at: https://tntcat.iiasa.ac.at/CLIMACAP-LAMPDB/.

[3] For a detailed description of why these differences exist, see Chaturvedi et al. (2012), which reviews data sources used in the Asian Modeling Exercise.

Table 1
Data sources for models participating in LAMP and CLIMACAP.

Model	Population	GDP	Primary energy	Emission factors
ADAGE	UN	GTAP, IEA, IMF	GTAP, IEA	EPA, IEA, EDGAR, CDIAC
EPPA	UN	GTAP, IMF, NBSC	GTAP, IEA	EPA, BP, IEA
GCAM	UN	WB, UN	IEA	CDIAC,IEA
IMAGE	UN	WB, UN	IEA	IEA, EDGAR
iPETS	UN	GTAP	IEA	IEA
MEG4C	DANE	MHCP	N/A	Colombias National GHG inventory
MESSAGE-Brazil	UN	IEA	National energy balance	Brazilian National Communication, IPCC
Phoenix	UN	GTAP, PWT	GTAP, IEA	GTAP, CDIAC
POLES	UN	WB	IEA, Eurostat, Enerdata	IEA, EDGAR
TIAM-ECN	UN	WB, IEA and national statistics	IEA and national statistics	IEA, EDGAR, EPA
TIAM-WORLD	UN	IMF	IEA	IEA

processes – we explore variation across models. Fig. 2 shows the difference (in percent) between 2005 and 2010 base year results submitted by the modeling groups and 2005 and 2010 historical data from the same reference data source as in Fig. 1. The variation between modeling results and historical data exists for a number of reasons:

1. While the CLIMACAP-LAMP exercise has adopted 2005 as the base year to standardize model reporting, this is not the base year for some models requiring modeling teams to extrapolate to 2005.
2. Models may be using different data sets or different versions of the data from a particular source to parameterize the model.
3. Differences in model specification, particularly for energy and emissions, may make a straight comparison across models and with historical data difficult.

The models participating in CLIMACAP-LAMP adopt either 2004, 2005, or 2010 as their base year. The four computable general equilibrium (CGE) models (ADAGE, EPPA, iPETS, and Phoenix) use the Global Trade Analysis Project (GTAP) v7.1 database for calibration, which is based on 2004 data (Narayanan and Walmsley, 2008). For these models, exactly reproducing the 2004 base year data set is a key aspect of model calibration. To generate the 2005 data required for CLIMACAP-LAMP, the models are stepped forward one year, with the assumption that this should still provide fairly accurate results. Differences do arise, however, and may be the result of variations in model specification as well as the modelers' choice of additional data sources and assumptions required to step the model through time. For instance, for use in other applications, ADAGE uses secondary data to grow the balanced GTAP data from 2004 to 2010, and rebalances to represent a 2010 base year. Thus, ADAGE adopts a 2010 base year rather than 2005. Aside from the CGE models, LEAP-FB and MESSAGE-Brazil adopt 2010 as their base year, while the remaining modeling teams adopt 2005 as their base year, which can be calibrated to historical data over a number of years. For IMAGE, the notion of base year is a little less well defined, as the model starts is calculations in 1970, while it partly uses historic data for the 1970–2010 period. Energy use and CO_2 emissions are model output. The variation observed across these models, therefore, may be the result of differences in data sources, as highlighted in Section 2.1.

There seems to be the most agreement, both across models and across data sources, in estimates of population, which can be expected given that all but one of the models report using the UN estimates. Mexico is the one region exhibiting the most variation, with a number of models reporting population estimates that are approximately 4%

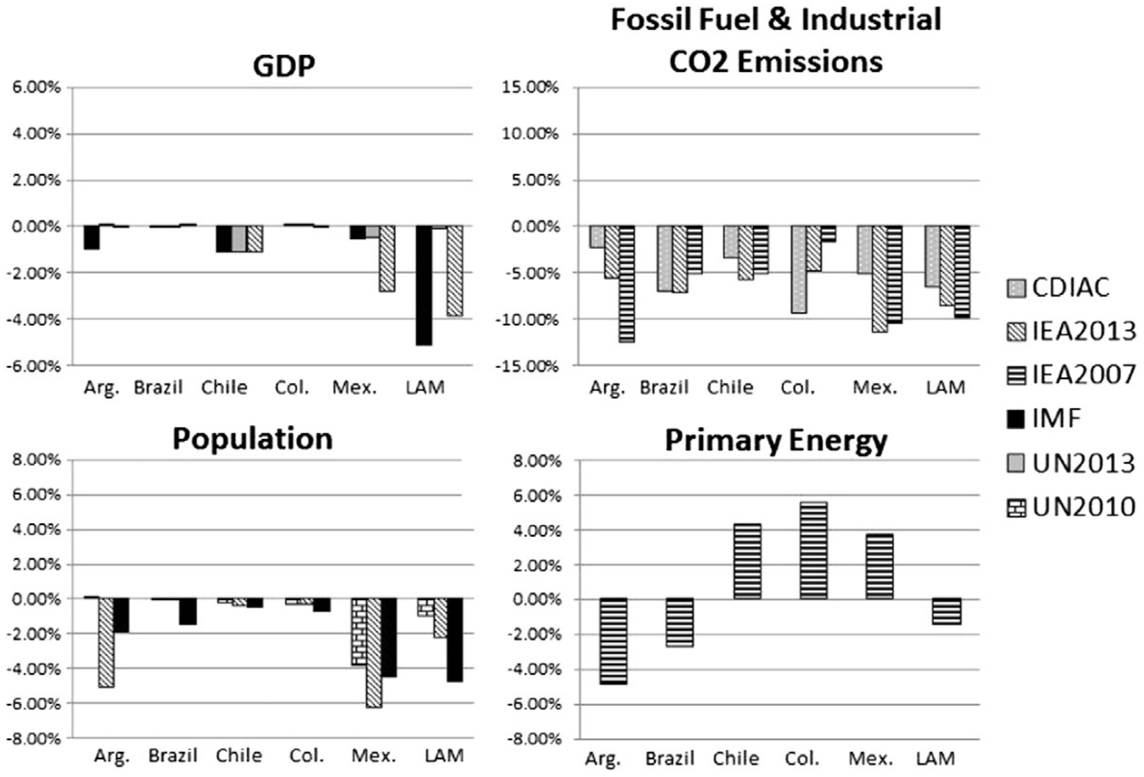

Fig. 1. Variation across data sources used for model calibration. The reference data source for GDP is the World Bank (2014); the 2013 UN revision (UN, 2013) for population; the CDIAC data base (Boden et al., 2013) for CO_2 emissions from fossil fuel combustion and industrial sources (including natural gas flaring and cement production); and IEA (2013a,b)for primary energy. Reference year: 2005.

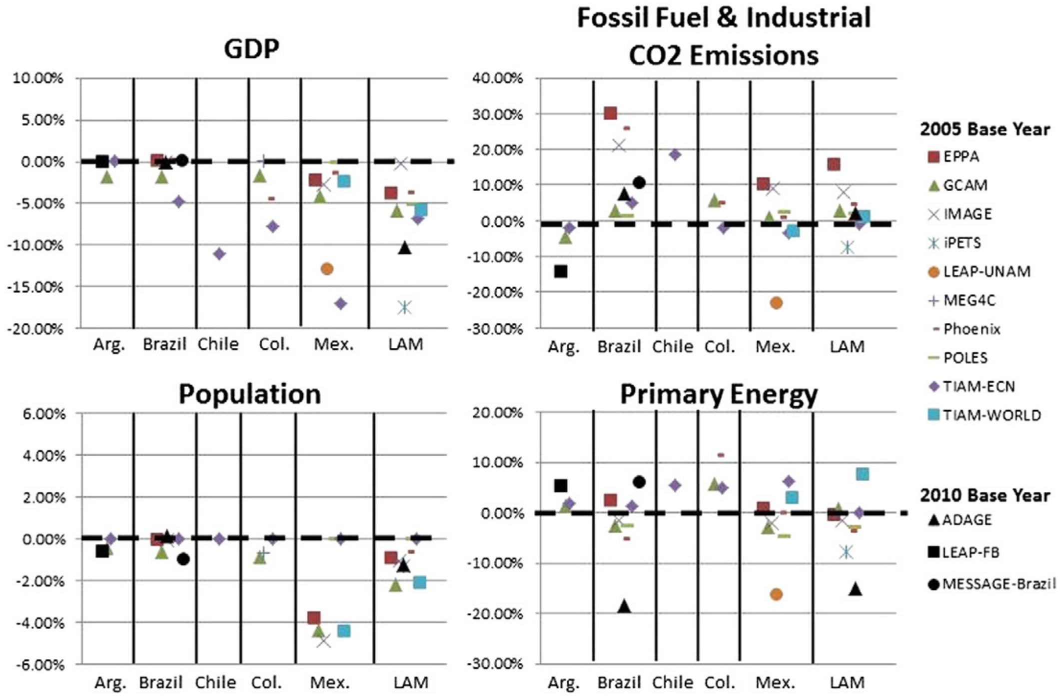

Fig. 2. Variation between reference data and the base-year results, either 2005 or 2010, submitted by models participating in the LAMP and CLIMACAP projects. The figure does not show the difference between the 2005 and 2010 reference data; rather each model's data point is relative to its respective base year.

below the UN 2013 revision estimate and the remaining models reporting estimates equal to the UN 2013 revision estimate. It appears that this is the result of the UN revising previous estimates, and the models not adopting the revision yet, as evident in Fig. 1. UN estimates from the earlier 2010 edition are 3.84% below the 2013 revised estimates. The aggregate LAM population data for most models are also lower than current estimates, as shown in Fig. 1.

With a few exceptions, most models that take GDP as an exogenous input are using 2005 estimates from the World Bank. The largest differences between 2005 GDP model estimates and the World Bank GDP historical estimates are reported for the aggregate LAM region. This is also the region with the largest degree of variation across data sources.

Primary energy estimates are compared to historical primary energy estimates from the IEA (IEA, 2013a,b), the source used by most of the models.[4] The majority of reported primary energy data fall within 10% of the IEA estimate. The results reported for Chile and Colombia are high and appear to be close to the 2007 IEA estimate. This explanation does not hold for the remaining regions, where model primary energy results are both above and below the current IEA estimates and not consistently in line with the 2007 publication. Recognizing that the aggregate primary energy data in Fig. 2 does not provide any information about the composition of a region's energy and or insight into how demand may change over the course of the core baseline scenario, Section 3.3 provides the base year primary energy data by fuel and shows how energy mix is expected to change throughout the core baseline scenario, and Section 5 compares the model results to historical data.

There is much less agreement across models and data sources for CO_2 emissions than for population and GDP. In Fig. 2, the CDIAC emissions estimate is compared to the models' reported emissions from fossil fuel combustion and industrial processes. The models are reporting CO_2 estimates that are either close to the CDIAC's historical estimates or notably higher. Many of these models report using IEA data as a reference, but for the reasons noted in Section 2.1, we would expect the model generated emissions to be lower, not higher, than the CDIAC estimates. Differences in model specification may be the primary reason for this variation. First, all models are tracking emissions from fossil fuels, but there is variation across the models as to how this is done (see Table 2 for detail). In most of the models in this exercise, emissions are determined endogenously by applying fuel-specific emission factors to estimates of fossil fuel consumption by energy type. Ideally, these emission factors should vary across regions, but with the exception of four models, many models use identical emission factors for all regions. Second, within the industry sector, some models are not tracking emissions from gas flaring and cement production or the estimates are included in aggregate emissions and cannot be reported separately. In the former case, we would expect their emissions to be lower than the reference historical estimates from CDIAC and close to each other in Fig. 2. Another large source of variation has to do with the specification of land use change, but we have tried to minimize this difference by only using emissions from fossil fuel combustion and industrial sources within this section. Models tracking land use change and the corresponding emissions may report total emissions that are higher or lower than the fossil fuel and industrial emissions reported here. Finally, some models report emissions from biomass fuels while other models make a simplifying assumption that on net emissions from these sources are zero. A model reporting emissions from biomass fuels (i.e. a model that reported “yes” in the bioenergy column of Table 2) would have an additional source of emissions from industrial processes that use biomass fuels and from the electricity generated by biomass than a model that does not track emissions from bioenergy. Models that answered “no” in the bioenergy column may track the use of biomass fuels including electricity by industry and households, but they would report a zero for the emissions from this energy source. This difference may explain some of the variation across models and the higher estimates relative to the reference emissions estimates.

While the variation discussed in this section may make comparing the model results challenging, it is not necessarily a problem that has to be fixed. Some of the base year variation is due to differences in the models' referenced historical data; a true source of uncertainty that cannot be settled within this exercise and standardization would create a false sense of certainty. Other base year variation may be due to differences in the

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[4] Note that primary energy in this study is defined as direct equivalent, which means that electricity generated from nuclear and non-biomass renewables is represented as the electricity output. This is opposed to primary equivalent, in which these technologies would be represented with a similar efficiency loss as fossil fuel power generation.

Table 2
Participating models' CO_2 emissions detail.

Model	Calculated endogenously?	Factors vary by region?	Tracking emissions from:			
			Land use change	Natural gas flaring	Cement Production	Bioenergy
ADAGE	Yes	Yes	Yes	No	No	Yes
EPPA	Yes	No	Yes	No	Yes	Yes
GCAM	Yes	No	Yes	Yes	Yes	Yes
IMAGE	Yes	No	Yes	Yes	Yes	Yes
iPETS	Yes	Yes	No	No	No	No
MEG4C	Yes	–	No	No	No	No
MESSAGE-Brazil	Yes	No	No	Yes	No	Only BioCCS
Phoenix	Yes	Yes	No	No	No	No
POLES	Yes	Only for transport liquid	Yes	No	Yes	No
TIAM-ECN	Yes	Yes	Yes	Yes	Yes	Yes
TIAM-WORLD	Yes	Yes	Yes	Yes	Yes	Considered CO_2-neutral

construction of the model or the fact that some models have not updated their base year parameters to the most recent estimates. A final source of variation across the models is the system boundaries which determine which emission sources are included or excluded.

The remainder of this paper will explore differences in core baseline projections across the models participating in the CLIMACAP-LAMP project. Some of the base year variation discussed in this section may perpetuate through the model results, leading to a range of core baseline scenarios across models. To analyze the impact of the base year variations on future projections, the ESM provides a series of figures (Fig. S2–S5) that harmonize the model projections to the year 2010.[5] These figures indicate that the range of set of core baseline projections does not change significantly when the base year uncertainty is removed.

3. Overview of core baseline scenarios

A dataset of selected output from 13 participating models (ADAGE, EPPA, GCAM, IMAGE, iPETS, LEAP-FB, LEAP-UNAM, MEG4C, MESSAGE-Brazil, Phoenix, POLES, TIAM-ECN and TIAM-WORLD) was generated for the CLIMACAP-LAMP project.[6] There are two versions of the TIAM model with different regional coverage (TIAM-ECN and TIAM-WORLD) and the iPETS model provides two baseline scenarios (iPETS-SSP2 and iPETS-SSP5). In this section we present the set of core baseline projections for 2005–2050 for the world, Latin America as a whole, Mexico and Brazil. Additional information for several Latin American countries is available in the dataset, and available in the ESM.

As part of the exercise, each modeling team was free to choose its key model assumptions, such as economic and population growth rates, energy efficiency improvements and technology development. Therefore, some differences in the results are due to different model structures, while others are due to different assumptions regarding future social, economic, and technological development. In addition, no harmonization was made for the present and future energy and environmental policies in these core baseline scenarios. For example, some models include regulatory mechanisms related to renewables, biofuels and land-use, while others do not. The appendix provides an overview of which policies are included in the core baseline scenarios. Many of the participating models have global coverage with regional disaggregation; however, some models focus solely on particular Latin American countries. The results for Latin America from the global models are also affected by socioeconomic development in other world regions. In this paper, we use the word ‘projection’ for the scenario results of the models, but it is worth noting that population and GDP are assumptions taken from other models or projects for most models and are not actually projected by the models in the CLIMACAP-LAMP project.

3.1. Population

Fig. 3 present population projections from the core baseline scenarios of the set of participating models. The figure also provides ranges of population projections (denoted by the shaded area) from the recent Shared Socioeconomic Pathways (SSPs) exercise that defines five possible paths that human societies could follow over the next century (Ebi et al., 2013; O'Neill et al., 2014; van Vuuren et al., 2014). The ranges do not indicate probabilistic properties; instead, they simply indicate how the future might unfold in different scenarios. The global population grows from approximately 6.5 billion people in 2005 to 8–8.5 billion in 2030 and to 8.5–9.7 billion in 2050. The range of population projections from the CLIMACAP-LAMP participating models is similar to the range of population projections in the SSPs. The ranges are driven by assumptions regarding fertility and mortality rates. Latin America's population is projected to grow from about 560 million people in 2005 to about 650–720 million in 2030 and to about 650–810 million in 2050. Similar to the global projections, the range of Latin America's population projections from the participating models is similar to the SSP range. Population projections for Mexico and Brazil have similar tendencies to the world and the aggregate Latin America region. None of the models project an increase in population growth for 2005–2050. Most of the models show a slowdown in population growth after 2030 due to a decline in fertility rates.

3.2. Economy

The global economy is growing over time both in absolute and per capita terms as shown in Figs. 4 and 5. As shown in Fig. 4, gross domestic product (GDP) is expected to grow by two to four-folds between 2005 and 2050. Initially, the participating models project a wider range of GDP in comparison to the SSPs partly due to differences in base year (2005) GDP values across models. After 2030, however, the SSPs project a wider range in GDP, especially in the higher economic growth scenario. We apply market exchange rates (MERs) to GDP projections in order to compare and aggregate GDP across regions. For the purpose of comparison, SSP projections for GDP are converted from their original purchasing power parity (PPP) values to MER values using the base year PPP factors (World Bank, 2014), where a convergence of future PPP values to one is assumed, based on a country's GDPpc growth compared to the US GDPpc growth.

Fig. 5 shows the range of model projections for GDP per capita. By 2050 the models project world GDP per capita to be in the range of \$12,000–22,000[7]; in the range of \$11,000–22,000 for Latin America; in the range of \$12,000–31,000 for Mexico, and in the range of \$10,000–\$26,000 for Brazil. All of the participating models project a population that is getting wealthier over time; e.g., in 2005–2010,

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[5] Here, the year 2010 was chosen rather than 2005, in order to include several models for which 2010 is the earliest reported year.

[6] The CLIMACAP-LAMP database with a limited number of variables is available at https://secure.iiasa.ac.at/web-apps/ene/LAMPDB/.

[7] In this paper, monetary units are in year 2005 US\$, unless stated otherwise.

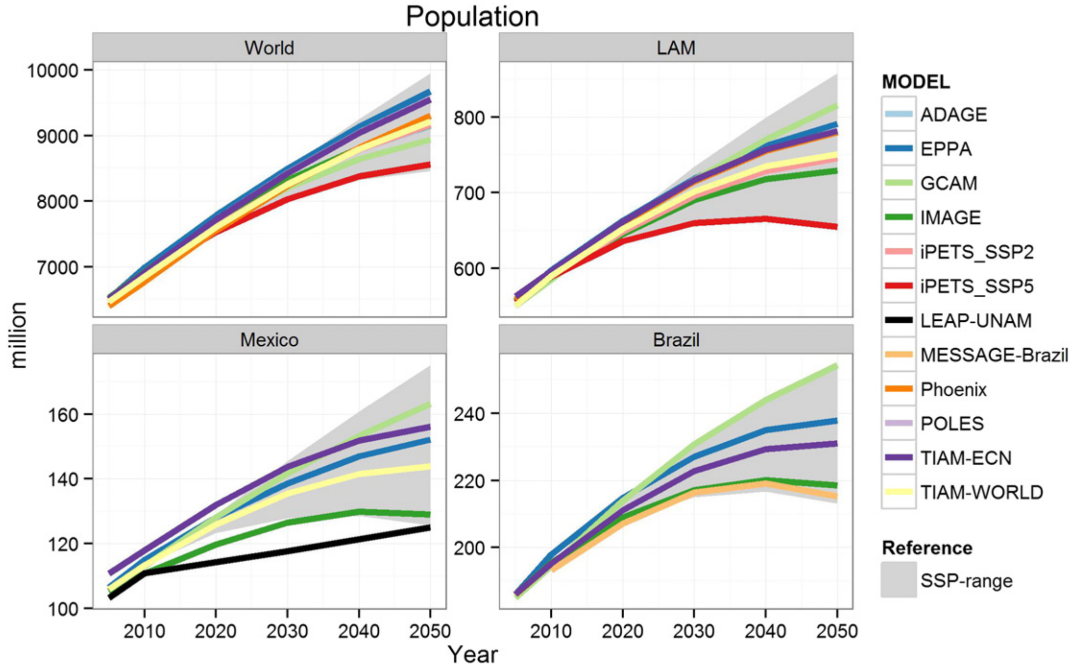

Fig. 3. Population projections in the core baseline scenarios of the participating models. Shaded area indicates the range of SSP projections (KC. and Lutz, accepted for publication). Please note that the y-axes of these figures are all different, and truncated for readability.

GDP per capita was lower than $10,000 in all countries and regional aggregations.

3.3. Energy

Fig. 6 compares the composition of primary energy use over time: historical data from 2005 (IEA, 2012a,b) and model projections for 2020 and 2050. Total energy use differs across the models and in some cases the differences are quite substantial both at the global and individual country levels. However, most of the models project a continuing reliance on fossil fuels (coal, oil, natural gas) throughout the period 2020–2050. In addition, most of the models project an increasing role of natural gas. Most of the disagreement between models is related to biomass energy use and the role of coal. This is partly due to different treatments of biomass in traditional and industrial use across models and partly a reflection of

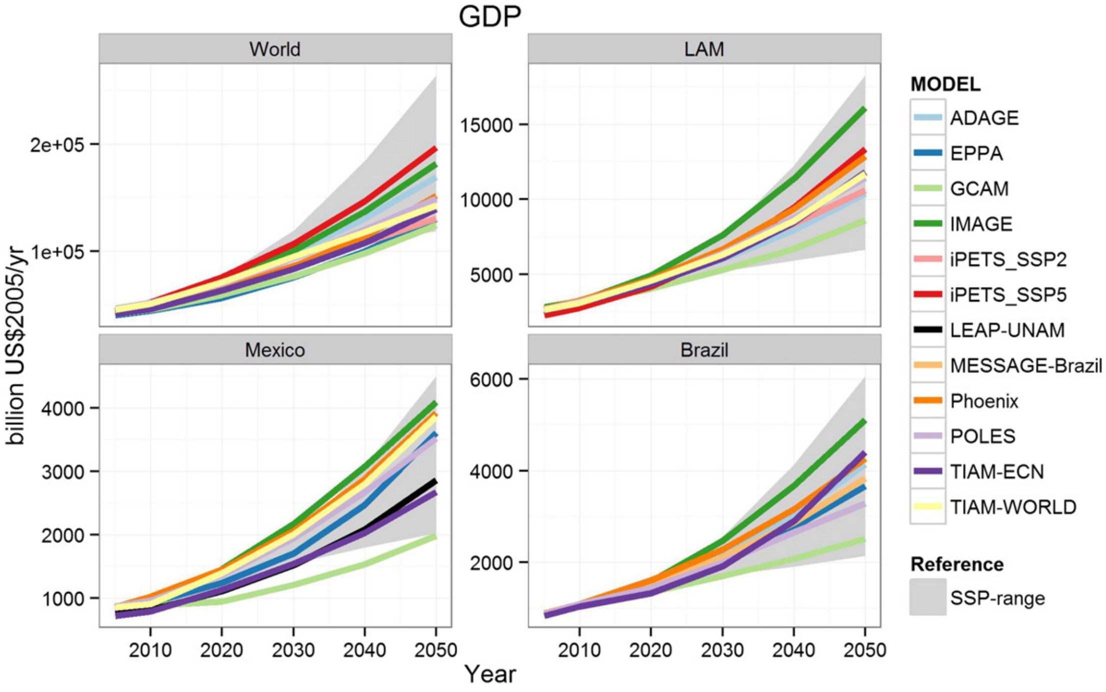

Fig. 4. GDP projections in the core baseline scenarios of the participating models. Shaded area indicates the range of SSP projections. Please note that the y-axes of these figures are all different, and truncated for readability.

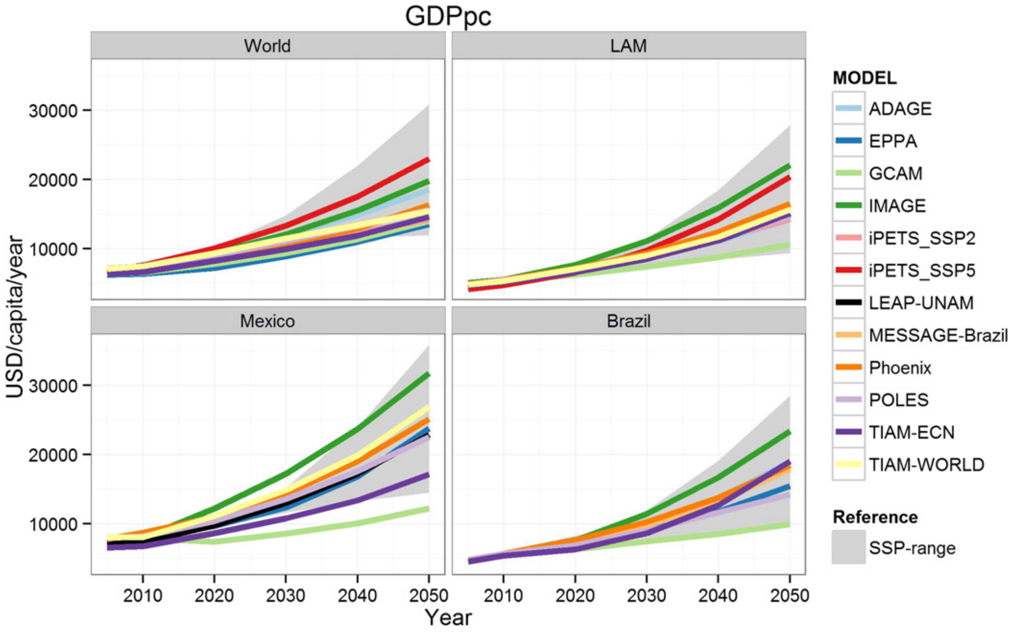

Fig. 5. GDP per capita projections in the core baseline scenarios of the participating models. Shaded area indicates the range of SSP projections. Please note that the y-axes of these figures are all different, and truncated for readability.

different assumptions regarding the future growth of biomass. By 2050 some models (POLES, in particular) project a substantial contribution from wind and solar energy. This variety between models is closely related to different directions of the changes projected in the power sector, where some models project a growing role for coal, whereas other models expect a larger role for natural gas and biomass energy (for a more in-depth discussion of the power sector see van der Zwaan et al., in this issue). Moreover, several models made assumptions on non-climate policies that influence the choice for energy sources (see the Appendix A for an overview of model assumptions). For instance, TIAM-WORLD made assumptions on air pollution constraints that limit the penetration of conventional coal power plants and IMAGE and TIAM-ECN made assumptions enforce the use of renewable energy sources based on existing policies.

3.4. Fossil and industrial CO_2 emissions

Carbon dioxide emissions steadily grow in all model projections for the core baseline scenarios, as shown in Fig. 7. Global emissions from fossil fuel use and industrial production grow from

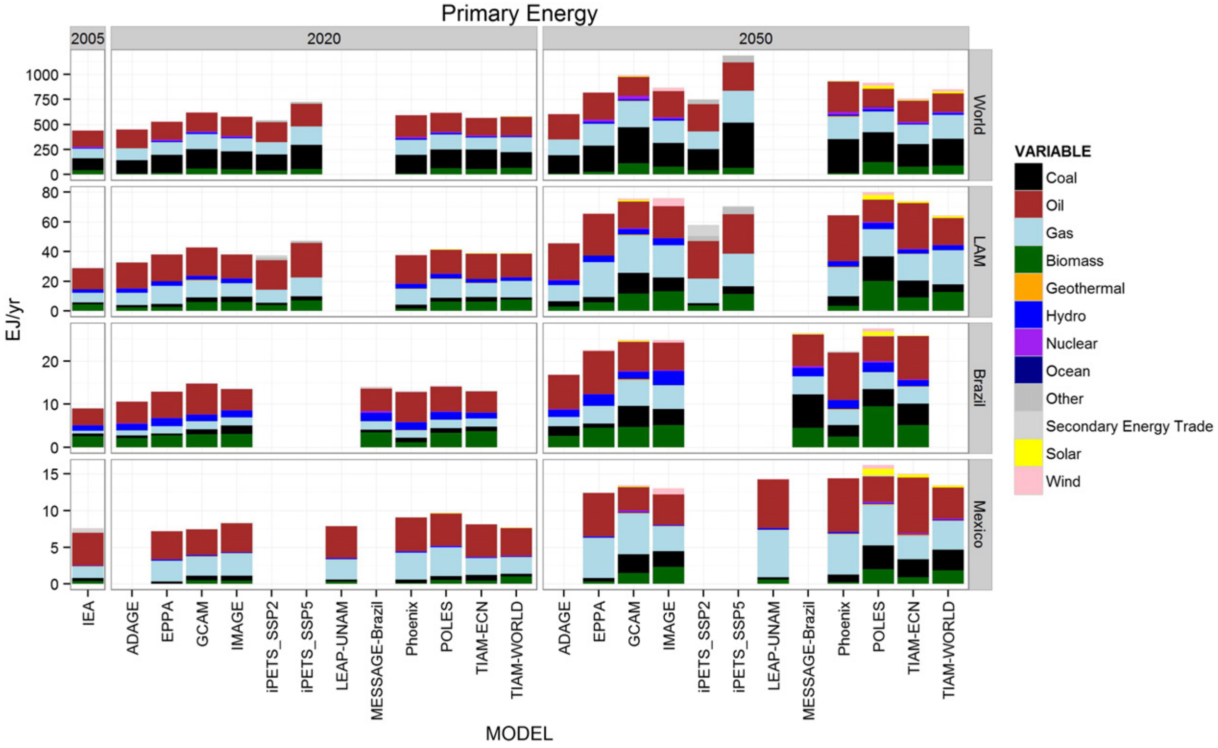

Fig. 6. Primary energy use for the world, Latin America, Brazil and Mexico in 2005, 2020 and 2050 in the core baseline scenarios of participating models.

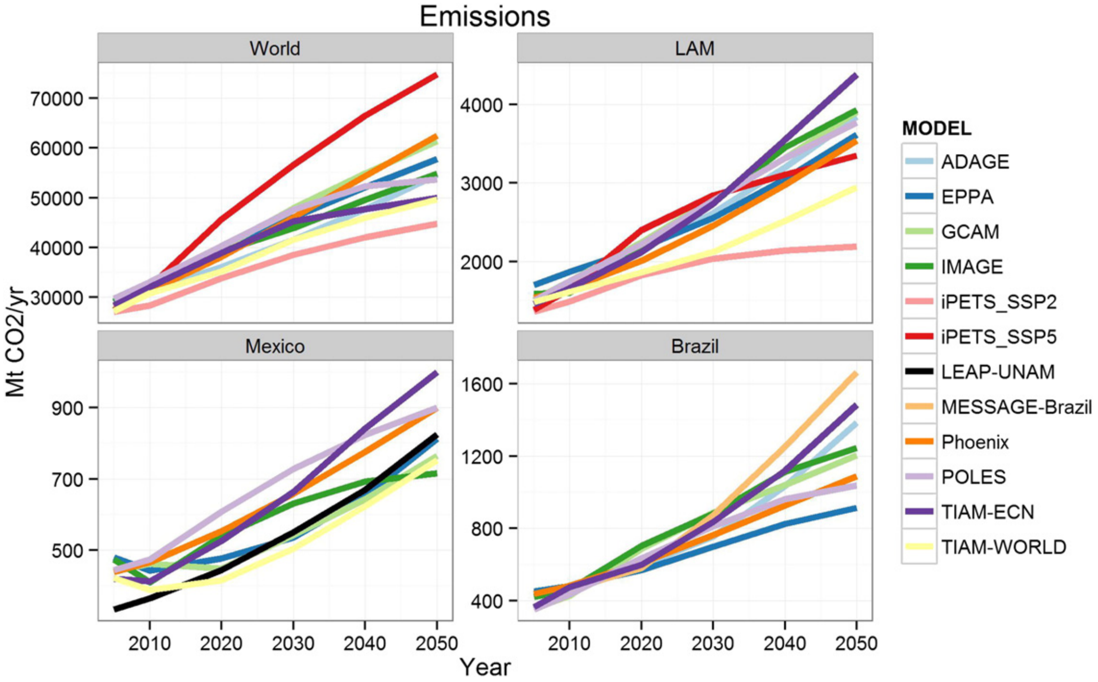

Fig. 7. CO_2 emissions from fossil fuels and industry for the world, Latin America, Mexico and Brazil. Please note that the y-axes of these figures are all different, and truncated for readability.

approximately 30,000 Mt CO_2 in 2005 to approximately 46,000–75,000 Mt CO_2 in 2050. Emissions in Latin America are projected to grow from 1400–1700 Mt CO_2 in 2005 to approximately 2200–4350 Mt CO_2 in 2050. Brazil and Mexico are the major contributors to Latin America's emissions. Brazil's emissions are projected to grow from approximately 400 Mt CO_2 in 2005 to approximately 800–1600 Mt CO_2 in 2050, and Mexico's emissions are projected to grow from approximately 450 Mt CO_2 in 2005 to approximately 700–1100 Mt CO_2 in 2050.

4. Decomposition of drivers

To understand what is driving the change in emissions over time, it is useful to decompose the relative contribution of the factors of the Kaya identity (Kaya and Yokobori, 1997):

$$C = P \times \frac{Q}{P} \times \frac{E}{Q} \times \frac{C}{E}$$

where

C Carbon emissions (Mt CO_2)
P Population (Million)
Q GDP (Billion US\$2005)
E Primary energy use (EJ)

By taking logs of both sides of the Kaya identity, the growth rate of carbon emissions is approximated by the sum of the growth rates of the Kaya factors.

The figures below compare the Kaya factors in two historical periods (1990–2000 and 2000–2010) and four forecast periods (2010–2020, 2020–2030, 2030–2040, and 2040–2050), including the range of model forecasts. The box in these figures represents the 25%–75% quartile of model results and the "whiskers" or lines represent the min and max of the model results.

From Fig. 8, we see that most of the growth in global carbon emissions (both historically and projected) is driven by increases in GDP per capita, population, and the carbon intensity of energy (CO_2/Energy), which is dampened slightly by negative growth in the energy intensity of output (Energy/GDP). These graphs also show the variation in these factors across models. Although population growth is consistent across most models (around 2% between 2005 and 2020), there is much more variation with respect to the other factors. Model variation is highest in the energy intensity of output (E/GDP) and GDP per capita. In particular, some models project a fall in energy/GDP while other models project a slight increase.

Looking at Latin America only (Fig. 9), we see that, except for population, the growth of each of the Kaya factors stays constant over time. Therefore, the fall in the growth of carbon emissions in Latin America is largely the result of a fall in population growth. Comparing projected versus historical values, we see that the models project a much more negative growth in energy intensity than what has been observed historically. GDP growth is also projected to be much higher than what has been observed historically.

There is significant variation across models. Some models are projecting large growth in the carbon intensity of energy, due to a shift in the composition of energy to more carbon intensive forms of energy over time (see Fig. 6), while some models project a more modest increase in carbon intensity. The range of projections for total carbon emission by 2050 of all participating models is between 2000 and 4500 Mt CO_2/year, although there is a clear clustering around 3500 Mt CO_2/year. Compared to similar analyses for the Asian Modeling Exercise (Blanford et al., 2012) this range of core baseline emission projections is narrower than for Asia. Fig. 9 shows that this is mostly due to counteracting assumptions on economic growth and energy intensity, both of which show large variation, but leading to a relatively small range for the growth in total CO_2 emissions.

In the cases of Brazil (Fig. 10) and Mexico (Fig. 11), we see a similar trend with the growth in carbon emission being driven largely by positive growth in the carbon intensity of energy and income (GDP/pop). However, the growth in emissions in Mexico is constant over time while the growth in emissions in Brazil is falling. In the case of Mexico, except for population, the growth in the Kaya factors is almost constant over the forecast period. This is in contrast with the historical period which shows an increase in the growth of energy intensity, but a fall in the growth of GDP per capita, the carbon intensity of energy, and population. In the case of Brazil, we see a fall in the growth of population and the carbon intensity of energy which is driving the fall in carbon emissions growth. The

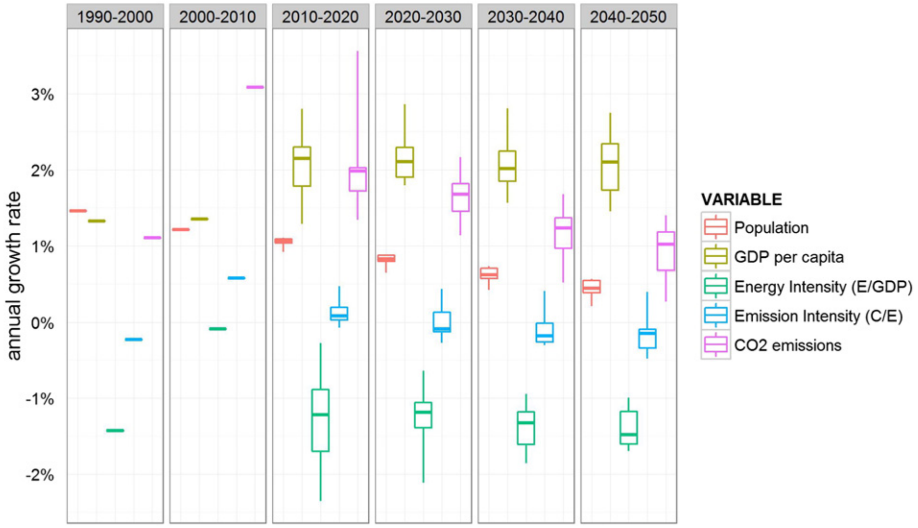

Fig. 8. Kaya decomposition of global core baseline scenarios.

growth in carbon intensity of energy in Brazil is falling due to a shift toward biomass energy and gas, as shown in Fig. 6. Variation in model results is significantly higher in the case of Brazil than in Mexico for all of the Kaya factors (except population). This is reflected in the large variation in projections of carbon emissions growth in Brazil across models.

5. A comparison of historic trends and core baseline scenarios

Historically, annual economic growth of Latin America as a whole ranged between 2% and 5% between the years 1990 and 2010, with an average annual growth rate of 3.2% (left panel in Fig. 12).[8] Brazil's economy is the largest in the region, making up approximately one third of total Latin American GDP, followed by Mexico's economy which makes up about one fourth. After 2004, Brazil's annual GDP growth rates exceed those of Mexico and are even twice as high as Mexico's in 2010. Other Latin American countries, such as Argentina, Chile, Venezuela, Peru and Colombia, experienced annual GDP growth rates above the average for Latin America over the last two decades. Comparing Latin America, and in particular Brazil, to the other BRIC countries, namely India, Russia and China, India and China experienced much higher economic growth between 1990 and 2010 than the other BRIC countries (Fig. 12). Russia experienced higher GDP growth after the year 2000. However, in per capita terms, Latin America's GDP per capita is still considerably higher than China and India — approximately five times higher than in India and about twice as high as in China in 2010 (right panel of Fig. 12). GDP per capita increased in Latin America from 4000 US$ in 1990 to 4600 US$ in 2000 and 5600 US$ in 2010. Among the wealthiest economies in Latin America, Mexico and Chile had the highest GDP per capita in 2010 with 8500 US$ and 8700 US$ respectively, which is roughly one third higher than GDP per capita in Russia and about 30% below the OECD average GDP per capita.

Primary energy intensity (defined as primary energy use per GDP) has been similar across Latin American countries and relatively constant over time, with an average primary energy intensity in Latin America of approximately 11 MJ/US$ over the past 40 years (Fig. 13). Since 2000 primary energy intensity in Argentina and Venezuela has been higher than the average in Latin America and lower than the average in Mexico, Colombia and Peru. This is partly determined by the fuel conversion efficiency of the whole energy sector, because the primary energy intensity decreases with increasing fuel conversion at constant GDP and final energy consumption. Hence, this indicator is positively influenced in regions with a high overall fuel conversion efficiency, e.g. due to vast deployment of hydro power. Vice versa, there is a negative effect on primary energy efficiency of GDP for regions which heavily depend on fossil fuels combusted in low-efficiency technologies, such as Venezuela, where energy consumption mainly relies on oil products, with a substantial share of fuel consumption in refineries, amounting to 20% in 2010, which is more than three times higher than the average across all Latin American countries (see Fig. S1 in ESM). Venezuela's share of renewable energy in total energy supply was only 10% in 2010, which is half the average share in Latin America. In contrast, Colombia covered 21% of total energy consumption with renewable energy.

Regarding the future development of the primary energy intensity of GDP all models in the exercise project a falling trend for Latin America. By 2020, energy intensity is expected to fall to an average of 8.6 MJ/US$, with a range of 8 and 10 MJ/US$ across models (Fig. 13). By 2050, energy intensity is expected to fall further to an average of 6.40 MJ/US$ and a range of 5 and 9 MJ/US$. Energy intensity in Brazil and Argentina is expected to be higher than the average of Latin America until the middle of the century. Energy intensity in Mexico and Colombia, however, is significantly lower than the average across Latin American countries. In the case of Mexico and Columbia, some models project energy intensities of almost 4 MJ/US$ by 2050. These low energy intensities are supported by improvements in the efficiency of energy conversion and the continuation of the deployment of renewable energy. In the case of Columbia, for instance, results from TIAM-ECN show energy efficiency improvements in the final demand sectors from 2010 until 2050 between 10% (commercial sector) and almost 30% (transport sector) and an increase of the average efficiency of electricity production by 12% in the same period. This development in the electricity production is facilitated by doubling of Colombia's hydropower capacity.

The analysis of Kaya identity in Section 3 provided several robust findings for key energy system indicators across the participating models. We find broadly agreement on the future development of the Latin American energy sector among the models, which allows us to combine multiple indicators based on the cross-model averages. The comparison of the main indicators for the energy sector in Latin America (Fig. 14) reveals that the 40% reduction in the energy intensity of GDP from 2005 to 2050 is accompanied by a 70% increase in primary energy consumption per capita, assuming no change in the emission intensity of primary energy (see left panel of Fig. 14). Hence, the emission intensity of GDP (here referring to CO_2 from fossil fuel and industry)

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[8] GDP growth calculated based on market exchange rates (MER) and a 5-year average.

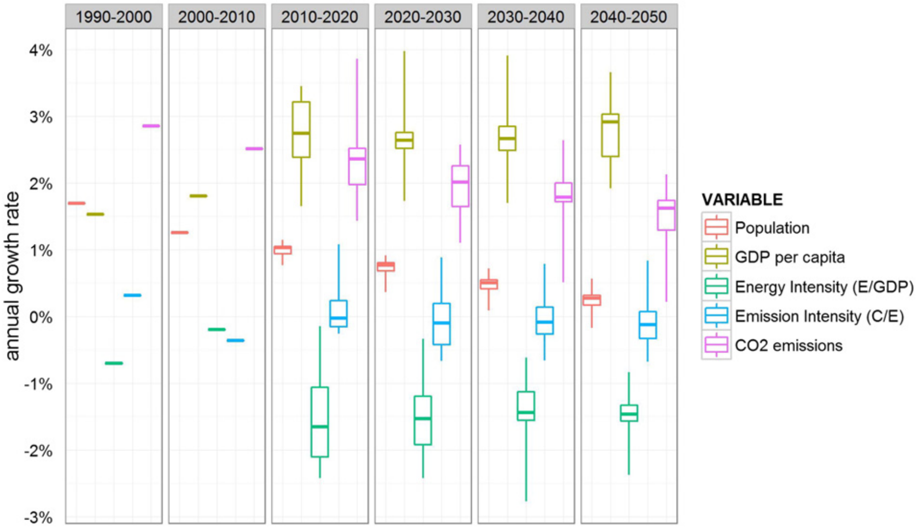

Fig. 9. Kaya decomposition of core baseline scenarios for Latin America.

declines similar to the energy intensity of GDP, and emissions per capita increase. Obviously, this is the result of higher economic growth in these countries with increasing GDP per capita. A similar trend can be observed on the global level—trends in Latin America are close to the world average except for CO_2 emissions intensity per capita and CO_2 emissions per GDP which are lower over the time horizon (see right panel in Fig. 14). The CO_2 emission intensity of primary energy stays below the global average until 2050 since fossil fuel conversion, in particular electricity generation from coal, is expected to play a minor role in the future energy supply mix in Latin America. The primary energy consumption per capita in Latin America reaches the global average around mid-century.

Across the set of participating models, we observe a more than doubling of total final energy consumption in Latin America by mid-century, with a marginal increase in the share of energy use for transportation purposes and slight decreases in the shares for industry and commercial/residential (Fig. 15). Electricity, which represented approximately 15% of total final energy consumption in Latin America in 2010, is expected to increase its role with up to a four-fold increase in final energy consumption by 2050 (Fig. 15). Largest increases in electricity consumption, both in relative and absolute terms, are observed in the residential and commercial sectors due to substantial growth of energy for cooling and air-conditioning as well as for information and communication technology.

6. Discussion and conclusion

In this paper, we examine base-year assumptions and core baseline projections of the set of models that participated in the CLIMACAP-LAMP project. Comparing base year model assumptions to historical data, we found relatively large differences between data sources for population, GDP, energy and CO_2 emissions. These differences largely explain the variation in base year results across the set of models. This variation across models should be taken into account when considering model projections, especially for CO_2 emissions and energy use. However, the databases are generally comparable to each other. Certainly, the range in different base year data does not have a strong impact on the range of future model projections.

We also found that the participating models span a broad range of population and GDP projections, comparable to the range of recently published drivers for the Shared Socioeconomic Pathways (SSPs). Population growth projections for Latin America, Brazil and Mexico range from 10 to 50% between the years 2010 and 2050. At the same time, GDP per capita projections range from a mere doubling to a

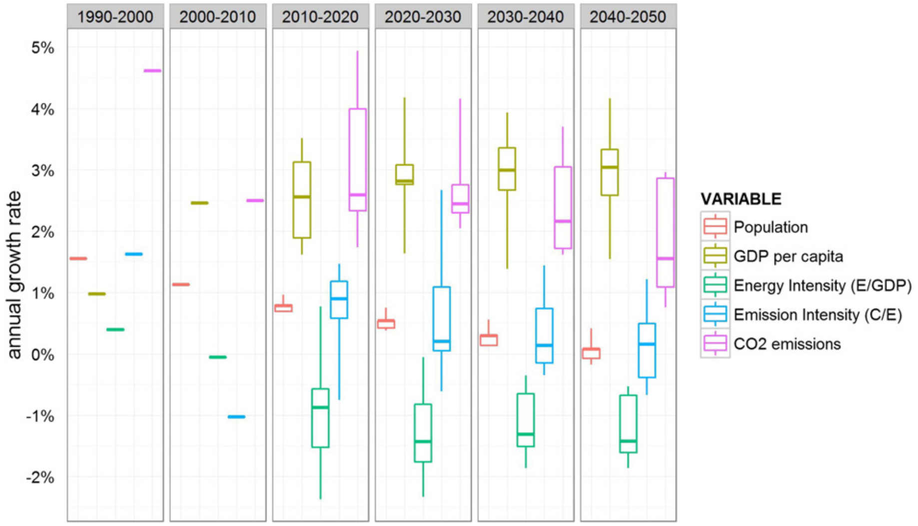

Fig. 10. Kaya decomposition of core baseline scenarios Brazil.

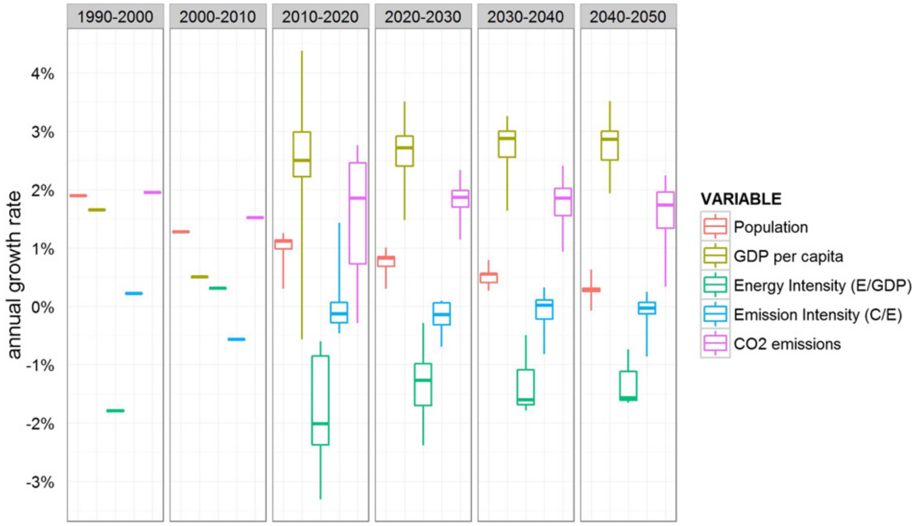

Fig. 11. Kaya decomposition of core baseline scenarios Mexico.

quadrupling of 2010 levels by 2050. This results in a 2–3 fold increase in primary energy use, leading to a 2–4 fold increase in CO_2 emissions from energy and industry between 2010 and 2050.

A Kaya-factor decomposition of the core baseline scenarios indicates that the projected increase in emissions in Latin American countries is mainly driven by GDP growth, population growth and a slight shift toward more carbon intensive fuels, and dampened by reductions in energy intensity.

Finally, we found that the trends from the core baseline scenarios reconcile on aggregate well with trends over the past few decades in Latin America. Projections of GDP growth are somewhat higher than historically observed, while energy intensity improvement is slightly higher than historical trends. Final energy mix, on the other hand, is expected to become more dominated by electricity over the next half century in the absence of climate policies.

The CLIMACAP-LAMP project did not assume any harmonization in core baseline scenario assumptions. As shown in Section 3, this led to a wide range of different assumptions across the models, especially with respect to population growth and economic development. None of these assumptions is considered more credible than another, and this wide range of scenarios only indicates the variation in assumptions made by the models in this project. In no way does it span the actual uncertainty range of potential futures in Latin American countries.

The broad range of emission projections in these core baseline scenarios does bring up an important issue: how useful are these core baseline scenarios as references for determining future mitigation commitments? Translating any percentage emission reduction below the baseline in 2020 or 2050 to an absolute emission number comes with a considerable uncertainty range depending on which baseline scenario is chosen as reference. Hence, baseline-based policies are an inherently uncertain and an unverifiable (or counterfactual) way of formulating long-term policy commitments. This can be improved by being extremely specific about which assumptions have been made

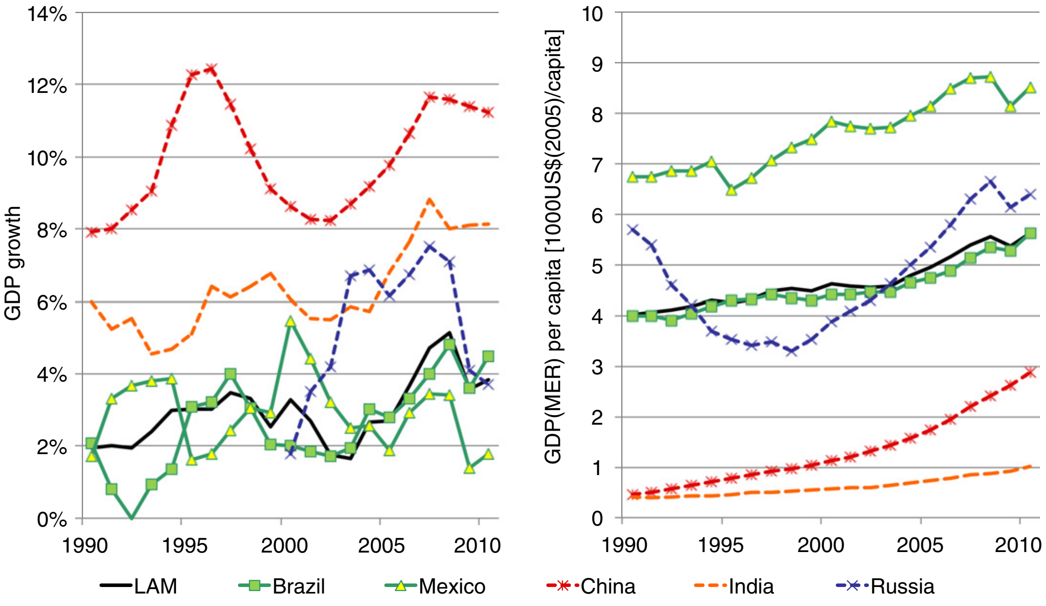

Fig. 12. GDP growth (left) and GDP per capita (right) in BRIC countries plus Mexico and the aggregate of Latin America World Bank (2013).

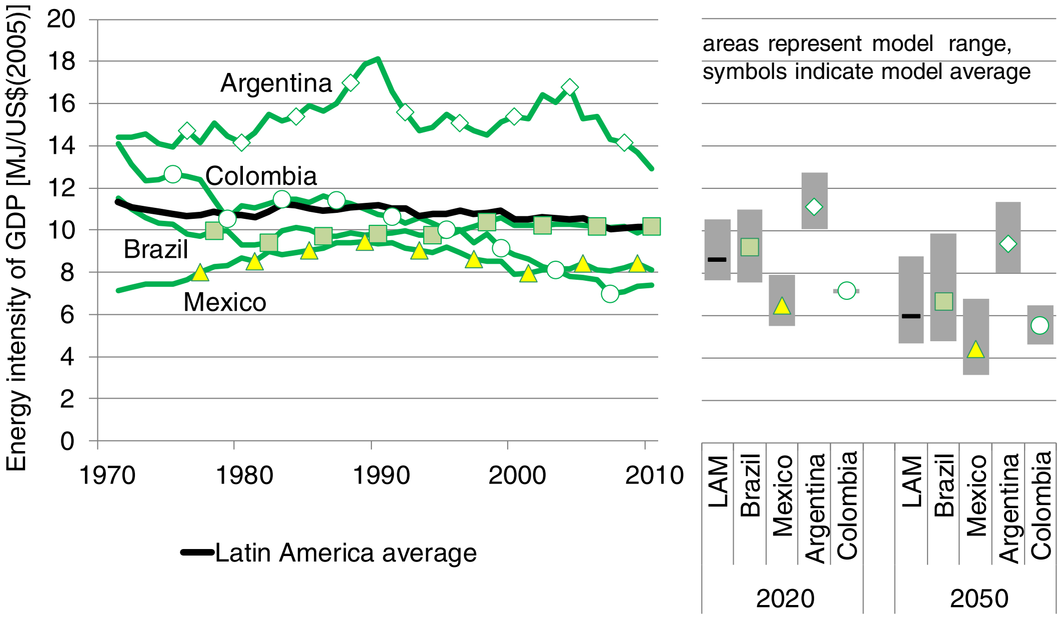

Fig. 13. Primary energy intensity (primary energy consumption per GDP (in MER terms)) in Latin America.

for the baseline on which the policy commitment was based, and by using such baseline-based commitments only for short term policy goals to avoid interference of unforeseen trends, such as higher or lower economic growth, or changes in demographic trends (Hood et al., 2014). For instance, the range in core baseline emissions from fossil fuel and industry for 2020 for Brazil is only 10–50% above 2010, but for 2050 this increases to a range of 80–150% above 2010 levels. The consequences of these baseline projections, and the efforts that are required to bring emissions down are further discussed in Clarke et al. (2016–in this issue).

Finally, further research may explore how global and regional or national models compare in their capacity to represent baseline trends, and energy and climate policies for Latin America. However, for this purpose, more regional and national models would need to be involved.

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Appendix A. Core baseline scenario policy information, as provided by the modeling teams

ADAGE	No explicit policies taken into account
EPPA	Assumed EU ETS and deforestation control policy in Brazil

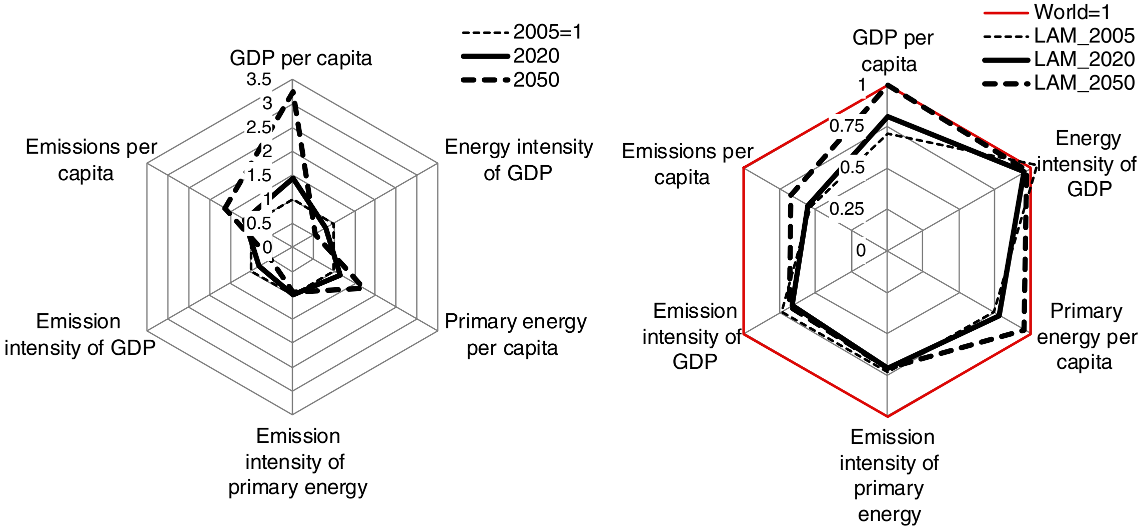

Fig. 14. Synthesis of energy and emission indicators for Latin America (LAM) based on model averages.

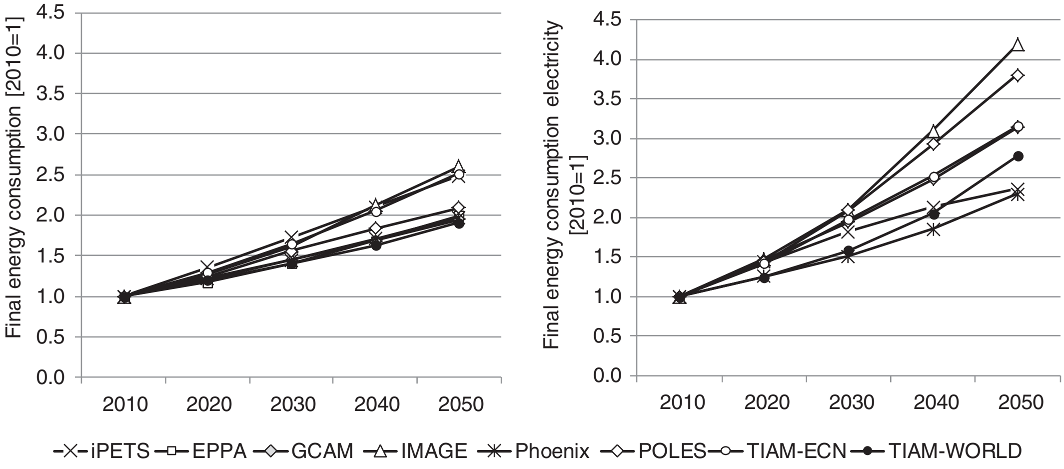

Fig. 15. Final energy consumption in Latin America (sector shares correspond to cross-model averages).

GCAM	No explicit policies taken into account
IMAGE	Air pollution policy influence emission factors, model includes policies forcing renewable energy shares based on existing energy policies.
iPETS	No explicit policies taken into account
MEG4C	No explicit policies taken into account
MESSAGE-Brazil	No explicit policies taken into account
Phoenix	No explicit policies taken into account
Poles	Some policies are included, but only in non-Latin America region (Europe, North America)
TIAM-ECN	Policies on energy production from renewable energy prior to 2010 assumed to be effective over the whole time horizon (implemented in terms of energy production from RE)
TIAM-WORLD	Limitation in the penetration of conventional coal power plants due to local air pollution constraints.

Appendix B. Supplementary figures

Supplementary figures to this article can be found online at http://dx.doi.org/10.1016/j.eneco.2015.02.003.

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