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# Global urbanization projections for the Shared Socioeconomic Pathways

## Abstract

The new scenario process for climate change research includes the creation of Shared Socioeconomic Pathways (SSPs) describing alternative societal development trends over the coming decades. Urbanization is a key aspect of development that is relevant to studies of mitigation, adaptation, and impacts. Incorporating urbanization into the SSPs requires a consistent set of global urbanization projections that cover long time horizons and span a full range of uncertainty. Existing urbanization projections do not meet these needs, in particular providing only a single scenario over the next few decades, a period during which urbanization is likely to be highly dynamic in many countries. We present here a new, long-term, global set of urbanization projections at country level that cover a plausible range of uncertainty. We create SSP-specific projections by choosing urbanization outcomes consistent with each SSP narrative. Results show that the world continues to urbanize in each of the SSPs but outcomes differ widely across them, with urbanization reaching 60%, 79%, and 92% by the end of century in SSP3, SSP2, and SSP1/SSP4/SSP5 respectively. The degree of convergence in urbanization across countries also differs substantially, with largely convergent outcomes by the end of the century in SSP1 and SSP5 and persistent diversity in SSP3. This set of global, country-specific projections produces urbanization pathways that are typical of regions in different stages of urbanization and development levels, and can be extended to further elaborate assumptions about the styles of urban growth and spatial distributions of urban people and land cover occurring in each SSP.

## 1. Introduction

A new conceptual framework for the development of long-term scenarios that integrate alternative climate and socioeconomic futures has been developed (Ebi et al., 2013; van Vuuren et al., 2013). The framework is intended to facilitate research on response options to climate change and also to enable better assessment of scientific literature on the topic by fostering studies that share common assumptions about climate change outcomes and socioeconomic development pathways. A key component of the scenario framework is the Shared Socioeconomic Pathways (SSPs; O'Neill et al., 2013). The SSPs are intended to be qualitative and quantitative descriptions of alternative societal and environmental development pathways over the 21st century, which would then be combined with alternative climate change projections and assumptions about mitigation or adaptation policies (Kriegler et al., 2013) to produce integrated scenarios of climate change mitigation, adaptation, and impacts.

The SSPs are important to scenario-based climate change research because key questions about climate change, including how difficult it would be to reduce emissions enough to meet a given climate change target, or how difficult it may be to adapt to the resulting climate change, depend critically on societal development. Scenario research therefore aims to address these questions while accounting for a broad range of possible societal development outcomes. The SSPs consist of five different qualitative narratives describing broad patterns of possible future development at the level of large world regions (O'Neill et al., this issue). In addition, they include quantitative pathways for key elements that are typically inputs to models used to project future greenhouse gas emissions, emissions mitigation costs, climate change impacts, and adaptation possibilities. Quantitative pathways for national-level population and educational attainment, based on the five SSP narratives, are described in K.C. and Lutz (2014 and this issue), and national-level projections of GDP growth are described in three additional papers in this issue. Here, we describe the development of a new set of global, country-specific urbanization projections for each of the five SSPs that constitute an additional quantitative element of the SSPs.

Urbanization is a key component of societal and environmental development (Grimm et al. 2008; Montgomery 2008) and virtually all world population growth (National Research Council, 2003; United Nations, 2010) and most global economic growth (Martine et al., 2008) over the next several decades are expected to occur in the urban areas of developing countries. Yet urbanization has not been included in most previous global environmental scenarios, including those from the Special Report on Emissions Scenarios (SRES; Nakicenovic et al., 2001) of the Intergovernmental Panel on Climate Change (IPCC) and from the Millennium Ecosystem Assessment (2005). Climate change studies in particular require consistent sets of global urbanization projections to support analyses of emissions and mitigation options (Krey et al. 2012; O'Neill et al. 2012; O'Neill et al. 2010) as well as of vulnerability to impacts (McDonald et al. 2011; McGranahan Balk and Anderson 2007; Moss et al. 2010; Parrish and Zhu 2009; Zhou et al. 2004).

Urbanization has generally been associated with faster economic growth and higher emissions both in analyses of historical data (Jones, 1989; Parikh and Shukla, 1995; Cole and Neumayer, 2004) and in future global (O'Neill et al., 2010) and regional (O'Neill et al., 2012; Krey et al., 2012) projections. It is important in interpreting the results of these analyses to define what is meant by "urbanization." The historical analyses tend to control for income growth, so that urbanization effects are distinct from income effects. In model-based projections, however, urbanization often has indirect effects on income growth, consumption patterns, and the efficiency of energy use, so that urbanization is defined as a broader socioeconomic phenomenon including not only the location of population in cities but also changes in consumption and production structure that frequently occur with the urbanization transition. This explains some of the differences in findings between these studies and arguments based on individual city analyses that urbanization *per se* has benefits related to energy use and emissions (Satterthwaite 2008; Dodman 2009).

The pace and form of future urbanization will also be a key factor in society's vulnerability to, and capacity to respond to, various challenges of climate change (UN-Habitat, 2006) including water stress (McDonald et al., 2011), flooding (McGranahan et al., 2007), heat waves (Zhang et al. 2009), and air pollution (Parrich and Zhu, 2009; Grimm et al., 2008). Alternative urbanization pathways may yield distinctive health consequences, given the tendency for rural populations in many developing countries to rely more heavily on solid fuels, which are an important source of indoor and outdoor air pollution (Jiang and O'Neill 2004; Pachauri and Jiang 2007; Krey et al. 2012). The large uncertainty in future urban expansion into protected areas may be a key challenge to conservation of biodiversity in many regions, and the substantial variation in the rate and amount of forecasted urban expansion across global regions points to the need for more detailed national or regional analysis (Guneralp and Seto 2013).

Existing global urbanization projections do not meet the needs of the design of SSPs. That is, there is no consistent set of global urbanization projections at the country level that extend over the whole 21st century and span a full range of uncertainty. The most notable set of global, country-specific projections is from the UN (United Nations, 2014) but has two main limitations: (1) it includes only a single projection and therefore cannot support the development of alternative societal development pathways; and (2) it extends only to 2050 and therefore cannot be used in longer-term analyses. Although the UN has begun developing probabilistic urbanization projections to help communicate the uncertainty associated with future urbanization (Alkema et al., 2011), these are not well suited to integrating urbanization into the deterministic approach of alternative future scenarios represented by the SSPs. The only other global urbanization projections, from the International Institute for Applied Systems Analysis (IIASA; Gruebler et al., 2007), extrapolate UN projections to 2100 and provide three alternative projections by making exogenous assumptions about long-term maximum urbanization levels. However, these projections do not capture uncertainty over the next few decades, a period of critical importance to urban transitions; are not clearly grounded in historical experience; and provide no information on migration flows or changes in age compositions implied by a given urbanization projection (Rogers, 1982; O'Neill and Scherbov, 2006), information that is important in integrated analyses of environmental impacts.

The urbanization projections presented here are designed to meet the needs of the SSP development process and interdisciplinary global climate change research more broadly. We produce alternative urbanization projections that span a plausible range of uncertainty by extending and modifying the method used by the UN (United Nations, 2010), which draws on historical experience with urbanization at the national level to derive single urbanization projection for each country of the world. While there are critiques of the UN's approach (Bocquire, 2005; Dyson, 2011; Becker and Morrison, 1999; Hardoy and Satterthwaite 1986), our modifications to the methodology address several shortcomings. For example, while the UN assumes that all countries eventually follow a single "global norm" relating differences in urban and rural growth rates to the level of urbanization based on historical data (United Nations, 1998), we define the "norm" separately for each country to allow for alternative outcomes and the possibility that urbanization trends in the long run may not be direct extrapolations of their past experiences due to different economic, demographic and institutional conditions (Satterthwaite 1996). We also employ the historical data twice to carry out a two-stage projection to 2100, allowing for the possibility of capturing multiple phases of the urbanization process over the century. Finally, we define nine alternative urbanization pathways (rather than a single projection) for each country based on the range of various historical urbanization experiences. We define urbanization projections for each SSP by choosing from among these alternatives for each country of the world, based on the qualitative descriptions of development pathways contained in the SSP narratives at the level of three categories of countries grouped by income. Results show that the world continues to urbanize in each of the SSPs but the degree of convergence in urbanization across countries differs substantially, with largely convergent outcomes by the end of the century in SSP1 and SSP5 and persistent diversity in SSP3.

In the next section, we describe our projection methodology and in section 3 evaluate the results relative to historical trends and other projections. Section 4 describes the results and our selection of urbanization projections to match each of the five SSPs. Section 5 discusses conclusions and future directions.

## 2. Data and Methods

The urbanization projections draw on a database of national-level urbanization that extends from 1950-2010 for 232 countries of the world (United Nations 2010). The UN database has widely recognized limitations; the principal one is that the UN retains the definition of urban used by each country, and that definition is inconsistent across countries and in some cases over time as well (Jones 2002). In addition, the database does not capture variations and changes in settlement patterns of intermediate conditions beyond the conventional rural and urban dichotomy (Jones 2002). Nonetheless, the database remains so far the most comprehensive and complete data source that can be used to draw lessons from historical experience and inform projections of future urban growth. While inconsistency in the urban definition across countries is an undesirable feature of the data, in our projections consistency over time is more important, and is less prevalent in the database. Given the limits of the data, we develop a relatively simple and aggregate approach to projection that is based on the UN's own approach but modifies aspects that are particularly important to long-term global scenario analyses.

In the UN model, the urbanization level for each country (i.e., the proportion of the total population that is urban) is projected as a function of the difference between the urban and rural population growth rates. A linear relationship between this population growth rate difference and the urbanization level itself is defined based on historical data. More specifically, the urbanization level ($PU_t$) can be defined in terms of the urban-rural ratio ($URR_t$, the ratio of urban population to rural population),

$$PU_t = URR_t/(1 + URR_t) \quad (1)$$

Changes in $URR_t$ and therefore in the urbanization level can be modeled as a function of the difference between the urban and rural population growth rates $urr_t$, where the growth rate difference is itself a function of the urbanization level:

$$URR_{t+1} = URR_t * e^{urr_t} \quad (2)$$

$$urr_t = f(PU_t) \quad (3)$$

where $f$ is the linear, empirical relation derived from the data (note that the fact that $f$ is linear does not imply that the fraction of the population that is urban changes linearly over time). Countries are assumed to converge to this global relationship over a 20-year transition period.

We adopt the UN's approach of assuming a linear relationship between the difference in urban-rural population growth rates and urbanization level, but modify the UN methodology by defining the relationship separately for each country (rather than using a single global norm) and for fast, central, and slow urbanization projections (rather than a single projection). Relationships between the urban-rural population growth difference and urbanization level for each country and projection are defined based on a set of reference countries that are drawn from the historical data (United Nations, 2010). Data from small island or city countries whose land areas are smaller than 1000 $km^2$ and populations in 2010 are less than 1 million persons are discarded, leaving 151 countries with urbanization records for the period of 1950-2010 as the core data set.

In order to select reference countries to develop the norm for a particular target country and projection, we take three steps (see Supplementary data for an illustration for the example of India). First, we choose from the database all countries that have ever achieved an urbanization level within 5 percentage points of the current level in the target country. This step identifies countries that were similar to the target country in terms of urbanization level at some time in the past. Second, in most cases we eliminate from this sample the 25% of countries whose urbanization growth rates over the decade prior to reaching the target urbanization level differ the most from the target country's growth rate. This step ensures that reference countries were similar to the target country at a certain point in time not only in terms of urbanization level, but also in terms of how fast they were urbanizing at that time. We do not limit the selection of reference countries further, for example by choosing countries from similar regions or levels of development, because it would produce insufficient sample sizes. Third, we divide the remaining sample into three different groups: the 25% of countries with the highest urbanization levels 30 years after they reached the target level, the 25% of countries with the lowest urbanization levels at that point, and the 50% of the sample in between. These three groups serve as the reference countries for defining the norm for the fast, slow, and central projections, respectively, for the target country.

The choice to distinguish fast, slow, and central reference countries based on their urbanization level 30 years after the base year was made on the basis of an analysis of the rank correlation of their urbanization levels over time (Supplementary Figure S2). The analysis indicates that a country's rank in terms of urbanization level as compared to other reference countries is positively correlated over time and is less likely to change significantly the farther into the future one looks. For example, for India's group of reference countries after step 2, the rank five years after the base year does not predict well the rank 25 years later (correlation coefficient = 0.65). In contrast, the rank 30 years after the base year predicts rank 25 years after that much better (correlation coefficient = 0.92). Thus, it would be ideal to distinguish fast, slow, and central reference countries using their urbanization level far beyond the base year. However, the sample size of countries that have a long enough time series of data to support such a distinction diminishes as the length of this time horizon increases. Considering both factors, we decided to use 30 years of prospective data to distinguish among fast, central and slow reference countries.

However, this set of reference countries is not sufficient to support a projection over a 90-year period, given the relatively short (60-year) historical record. For example, a country currently at a low urbanization level may go through several different regimes of growth: slow increases in urbanization, a fast takeoff period, and then a slowing as urbanization converges to a long term level. Using a single set of reference countries over a limited time period will frequently not be able to capture well these multiple regimes. We therefore adopt a two-stage projection approach to generate additional reference countries for use in the model (Supplementary Figure S3). Using the selected references countries from both stage 1 and stage 2, we create nine possible combinations of reference countries (fast, central, and slow in stage 1, and then in each case fast, central and slow in stage 2) and project the target country's urbanization level regressing the difference in urban and rural growth rate against the urbanization level (eq. (3); see Supplementary Figure S4a-b for examples of projections for India and China). From the nine possible combinations of plausible urbanization paths, we define our three projections of primary interest as the fast-fast, central-central, and slow-slow combinations over the two stages, which we refer to as our "Fast," "Central," and "Slow" projections. In order to produce numbers of people in urban and rural areas, these projections need to be combined with a population projection for each country, which in this case are the SSP population projections (K.C. and Lutz, this issue).

## 3. Evaluation of Projection Results

Validating long-term projections of socioeconomic factors like urbanization is difficult (Berkhout et al. 2002; van Lieshout et al. 2004), but such projections can usefully be evaluated against historical experience and other projections, and by evaluating the plausibility of outcomes for other variables (like migration) implied by the projections.

The wide range of urbanization outcomes represented by these projections is consistent with historical experience. Results for each country fall within the range of 90% of historical urbanization outcomes when compared to countries that at some point in the past reached a level of urbanization similar to that in the base year (Supplementary Figure S7a-d). Fast projections are below the 95th percentile, slow projections above the 5th percentile, and central projections within the 50% interval. This consistency is ensured by the methodology, which relates urbanization growth rates to urbanization levels for each country and projection based on the historical experience of other countries selected to the reference group. Figure 1 compares our projections to historical data for an average of one measure of the urbanization growth rate, the urban-rural population growth difference (United Nations, 1980; Preston, 1979), as a function of urbanization level. The Central projection generally represents the overall historical mean, while the Fast and Slow projection are near the upper and lower bounds of historical experience.

Evaluation against other projections indicates some similarities but also key differences that represent important improvements. For example, our Central projection is broadly similar to the UN projection through 2050: differences for all countries are within -10 to +8 percentage points at all times (see Supplementary Figure S6a-b). However, before 2030 our Central projection is generally higher than the UN projection, and afterwards it is generally lower, as illustrated in Figure 2 for the example of India and the World. The main reason for faster urbanization in our projection in the near term is that the UN assumes a 20-year transition period in which each country urbanizes largely at its most recent urbanization growth rate before converging to the “global norm”. In contrast, we assume each country urbanizes according to a pathway defined by a set of similar reference countries (see Data and Methods). The UN transition period approach has the benefit of ensuring a gradual evolution of urban growth, but has a cost in that it excludes the possibility of the types of rapid short-term change observed in many countries historically.

After the 20-year transition period, our Central projection produces generally lower urbanization than the UN projection, with more than 70% of countries having lower urbanization in 2050 than in the UN projection. Several existing studies have suggested that the UN projects urbanization growth rates that are generally too high (National Research Council, 2003; Alkema et al., 2011; Bocquire, 2005; Montgomery, 2008). We believe our Central projection is an improvement in this regard. The UN produces higher urbanization because it assumes all countries urbanize following a global norm after 2030, which is weighted toward the experience of countries in the early decades of the historical record, which generally experienced more rapid urbanization. In contrast, our projections use norms that are tailored to the circumstances of each individual country, and are therefore less susceptible to this unequal weighting. In addition, we use a second stage that allows for slow-down and saturation of the urbanization level, an aspect missing from the UN methodology.

Our projections differ from IIASA in that they span a substantially wider range of uncertainty over the next few decades (Figure 2). This is not only the case for individual countries such as India, but also true for the world as a whole. The IIASA projections focused on uncertainty in long-term outcomes (Gruebler et al., 2007) and were constrained to be close to a UN projection through 2030 (the horizon of UN projections at that time).

To further evaluate the plausibility of the urbanization projections, we calculate the gross and net rural-urban migrants for India and China implied by each of our urbanization projections. To carry out the calculation we use a multiregional population/urbanization projection model (Jiang and O'Neill, 2009; O'Neill et al., 2010) and the assumptions on total fertility rates and life expectancies under the medium variant of the UN Population Projection (United Nations, 2004). Figure 3 shows that the implied number of rural-urban net migrants in India and China differs significantly across different urbanization projections, but they are all within plausible ranges. Moreover, this information is valuable for integrating urbanization trends with corresponding migration flows as both causes and consequences of environmental changes (de Sherbinin et al. 2012).

## 4. Urbanization Projections for SSPs

To create urbanization projections for the SSPs, we assign either the Fast, Central, or Slow projection to the countries within each of three income-based country groups (see Supplementary data for definition of the groups) for each SSP. Assignments are made based on the assumptions about urbanization included in the SSP narratives (O'Neill et al., this issue) or based on reasoning we describe here that relates our choice to assumptions about other aspects of societal development in the narratives. Summaries of key features of each of the SSPs are included in the Supplementary Information.

*SSP1 (Sustainability)*: Fast urbanization in all country groups, associated with high income growth. Urbanization is driven in part by a desire for and promotion of environmentally friendly living arrangements, and compact urban form contributes to resource efficiency (Gossop 2011; Ewing and Cervero 2010).

*SSP2 (Middle of the Road)*: Central urbanization in all country groups, associated with moderate income growth. Consistent with the intent of the SSP2 storyline, urbanization proceeds at a moderate pace in all parts of the world, relative to the experience of similar countries historically.

*SSP3 (Regional rivalry)*: Slow urbanization in all country groups. Urbanization is constrained by slow economic growth in both rural and urban areas, the assumption in the narrative of limited mobility across regions, and poor urban planning that makes cities unattractive destinations (Mohan 1984).

*SSP4 (Inequality)*: Central urbanization in high-income countries, and Fast urbanization in medium- and low-income countries. Medium economic growth and attractive urban conditions in cities with high concentrations of the elite support urbanization in high-income countries, but rural-to-urban migration is moderated by rapid aging produced by low fertility rates (Kelley and Williamson 1984; Skeldon 2008). In contrast, high fertility in medium and low income countries produces age structures favorable to migration. In medium income countries, the assumption of medium economic growth is associated with the development of cities as manufacturing centers and engines of economic growth; therefore urbanization proceeds rapidly (Ledent 1982). In low income countries, pressure from rapid population growth and shrinking land and other resources act as push factors for rural outmigration (Oucho and Gould 1993; Abdel-Rahman et al. 2006). Meanwhile, the assumption of large income discrepancies within countries is assumed to apply particularly between rural and urban areas, serving as a pull factor causing large city-ward migration flows (Jiang 2014). Cities are subject to high inequality themselves, providing urban amenities for the elite but poor housing and infrastructure for the rest of the population, leading to massive expansion of slums and high unemployment (Fay and Opal, 1999).

*SSP5 (Fossil-fueled development)*: Fast urbanization in all country groups. Urban areas become attractive destinations due to rapid economic growth and technological change that allows for large-scale engineering projects to develop desirable housing. Increasing agricultural productivity and growing wealth leads to increased migration to cities and growth in urban labor, even when population growth rates decrease (Mohan 1984).

Figure 4a shows global urbanization results for each SSP based on these assumptions, combining the projections of urbanization level with the corresponding population projection for the SSP (K.C. and Lutz, 2014 and this issue). The world continues to urbanize in each of the SSPs relative to its current level of 50.4% urban, but outcomes vary widely. Urbanization is fast in SSPs 1, 4, and 5, reaching 92% (or nearly so) by the end of the century. In contrast, urbanization is slow in SSP3, reaching only 60% by the end of century, while in SSP2 the outcome lies between these two, at 79%.

The degree of convergence in urbanization also varies substantially across SSPs. Results aggregated into High, Medium, and Low income country groups show that in the fast-urbanizing SSPs (1 and 5 for all groups and also 4 for medium and low income groups), there is also substantial convergence with urbanization levels for all income groups ending up in the 90-96% range by the end of the century. However in the slow-urbanizing SSP3, urbanization levels remain as divergent as they are at the present time, with the low and medium income countries reaching only about 50% and 60% urban respectively in 2100, while the urbanization level for the high income group increases beyond 90%. SSP2 represents a moderate case with some convergence but much less than in the fast urbanization pathways, reaching 73%, 82%, and 94% for the low, medium and high income region respectively.

Convergence outcomes are driven principally by urbanization in low and middle income countries. Differences across SSPs by the end of century are within a range of only 6 percentage points in the high income region where the urbanization level is already high and the uncertainty in future urbanization trends is rather small (see Supplementary Figure S5). In contrast, many low income countries are at the beginning or in the midst of the urbanization transition, and there is therefore substantially more uncertainty in outcomes, reflected by a range of 46 percentage points in urbanization across SSPs in this country group.

Results aggregated to the level of continents (Figure 4b) illustrate these outcomes in more detail. Currently less urbanized Africa and Asia urbanize slowly under SSP3 and only reach 50% and 55% urban respectively by 2100 but urbanize quickly under SSPs 1, 4 and 5, reaching about 90% urban by the end of the century. For the more urbanized Europe and Latin America, the differences in urbanization across SSPs are much smaller, in the ranges of 83-96% and 88-96% respectively. We produce only a single projection for Australia/New Zealand and North America under all SSPs given their already very high urbanization level (see Data and Methods). Neither Africa nor Asia reaches the current level of urbanization in Europe or North America in SSP2 and SSP3, and in SSPs 1, 4, and 5 does so only after 2050.

Projections are distinctive across individual countries as well (Figure 4c). India has been one of the slowest urbanizing countries for the past several decades and just reached 30% urban in 2010. Our projections indicates a continuation of this slow pace in SSP3, implying that the country remains largely rural (44% urban by 2100), but a rapid near-term take off in SSPs 1, 4 and 5, leading to a 90% urbanization level in 2100. In contrast, China has been experiencing rapid urbanization and this trend continues for another four to five decades in SSPs 1, 4 and 5, or levels off in the near term in SSP3, leading to an urbanization level just over 60%. Nigeria, the most populous African country, reached a somewhat higher urbanization level than China's in 2010, but has recently been urbanizing more slowly. As a consequence, its projected urbanization proceeds somewhat slower, leading to similar outcomes to China's in each SSP. Uganda is among the least urbanized countries and demonstrates a very large variation in urbanization across different SSPs, by the end of century spanning outcomes of 25% in SSP3, 55% in SSP2, and 85% in SSPs 1, 4 and 5. Switzerland illustrates the opposite case. It had already reached 74% urban in the early 1990s and its differences in long-term urbanization levels across SSPs are much smaller.

Urbanization projection results for all countries can be downloaded from www.cgd.ucar.edu/ccr/urbanization/urbproj_all.xlsx.

## 5. Discussion and Conclusion

We have produced global, country-specific urbanization projections consistent with the five SSPs that can be used in scenario-based climate change analysis of mitigation, adaptation, and impacts. The projection methodology builds on previous projections by refining the manner in which historical experience is used to project future outcomes and by improving the characterization of uncertainty, particularly over the next few decades. These projections produce urbanization pathways that are typical of countries in different stages of urbanization, including outcomes in which urbanization stalls or is substantially delayed, as well as outcomes in which it proceeds rapidly to high levels. Evaluating the projections against historical data and other projections indicates that they are consistent with historical experience and improve on currently available global projections. Evaluating their implied rural-urban migration flows for two key countries (China and India) indicate that they result in plausible ranges of migration.

Projection results cover a wide range of uncertainty in both the level of urbanization and in the degree of convergence across countries, and these outcomes are consistent with the SSP narratives and assumptions about other factors such as GDP and population growth (Jiang 2014).

Future research could usefully improve and extend this work in a number of ways. First, a new set of projections could be produced using the same methodology but a new and improved data set from the UN Urbanization Prospects 2014 Revision which draws on updated information from the 2010-11 round censuses. Second,  assumptions about the forms and patterns of urbanization occurring in each SSP could be further elaborated, since these features are likely to be important determinants of the challenges to adaptation implied by each development pathway. Third, spatial versions of these projections could be produced that incorporate the distribution of population density; of people by characteristics such as age, income, and educational status; and of urban land cover across the landscape, all of which would be useful for research related both to emissions and to impacts and vulnerability. And last, to explore the effect of urbanization on emissions or impacts and vulnerability, variants of the SSPs with alternative (but still plausible) assumptions about urbanization could be developed to compare to outcomes based on the original SSPs. The full set of nine alternative urbanization projections presented here could be useful for that purpose.

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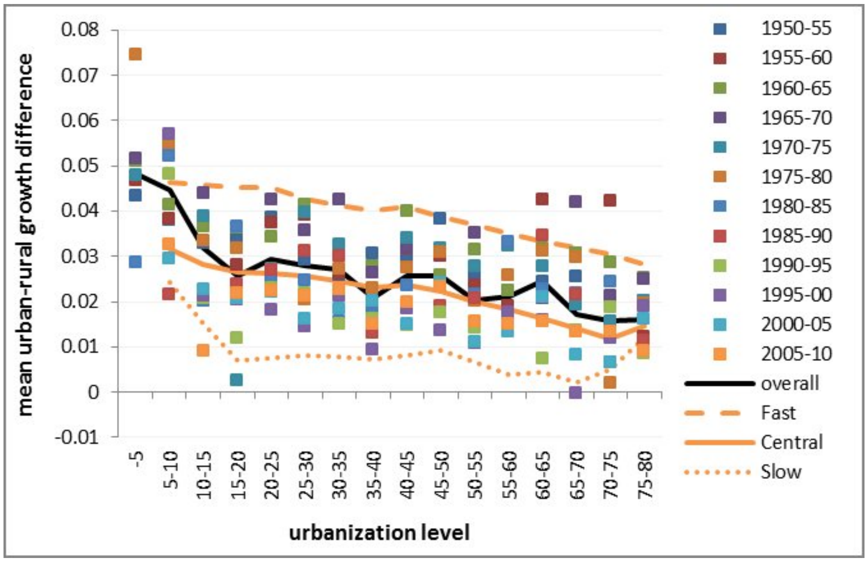
## Figure Legends

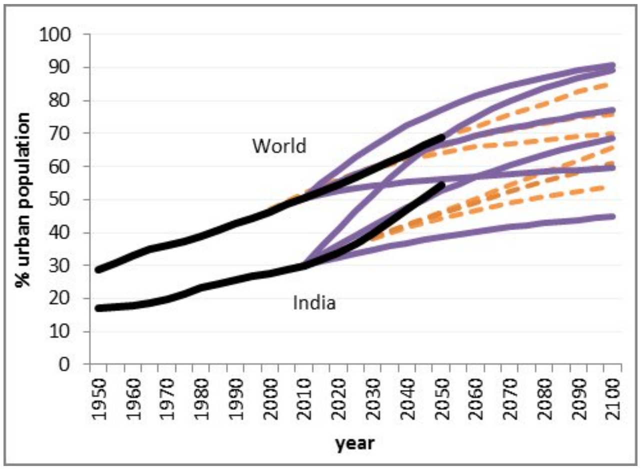
Figure 1 Mean differences in projected country-level urbanization between the Fast and Slow scenarios over time

Figure 2 Urbanization projections from NCAR (purple), the UN (black) and IIASA (orange dashed)

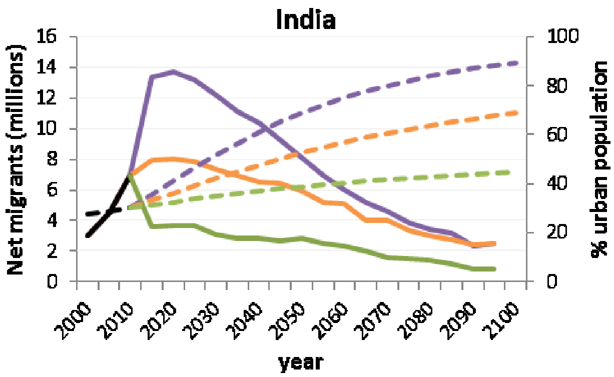
Figure 3 Implied net rural-urban migrants (solid lines) and projected urbanization level (dashed lines) under Fast (purple), Central (orange), and Slow (green) urbanization scenarios for India and China

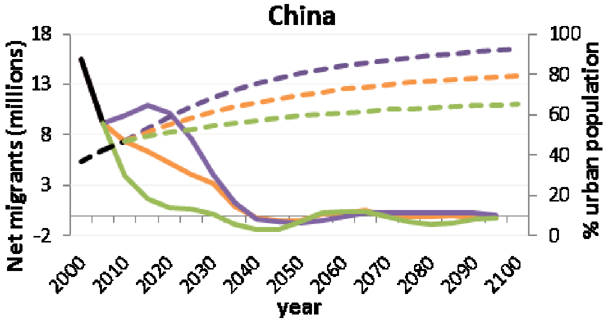
Figure 4 Urbanization projections for regions by level of development (a), continent (b), and selected countries (c) under the SSPs.

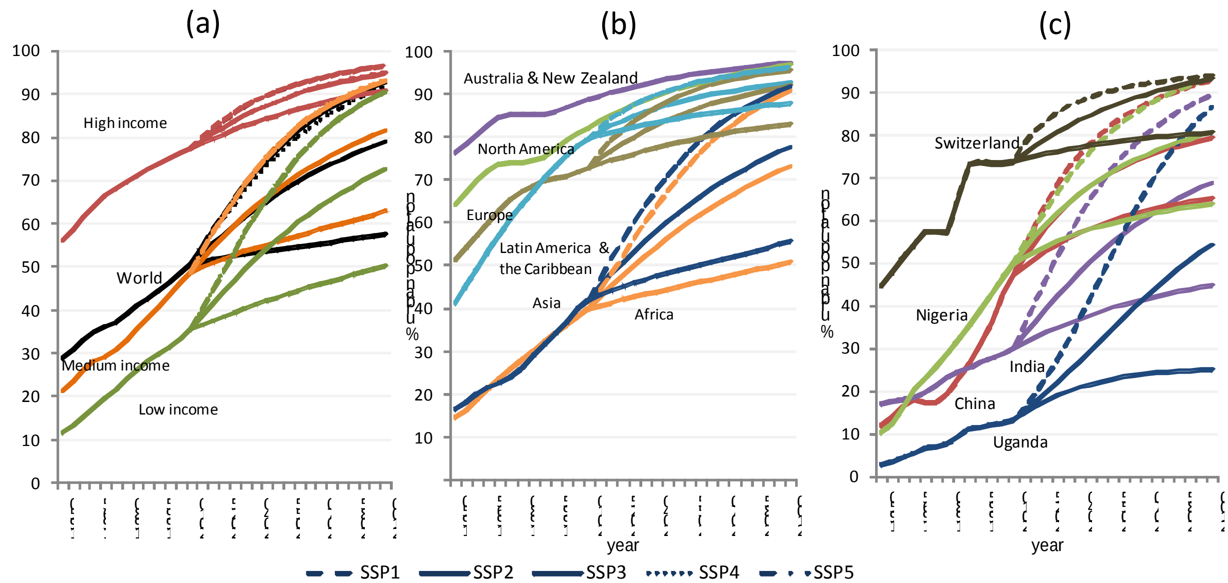

0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
mean urban-rural growth difference
-5
5-10
10-15
15-20
20-25
25-30
30-35
35-40
40-45
45-50
50-55
55-60
60-65
65-70
70-75
75-80
urbanization level
1950-55
1955-60
1960-65
1965-70
1970-75
1975-80
1980-85
1985-90
1990-95
1995-00
2000-05
2005-10
overall
Fast
Central
Slow



100
90
80
70
60
50
40
30
20
10
0
% urban population
World
India
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
year


India
Net migrants (millions)
% urban population
year
0
2
4
6
8
10
12
14
16
0
20
40
60
80
100
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100


China
Net migrants (millions)
% urban population
year
-2
3
8
13
18
0
20
40
60
80
100
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100




Note: For high income countries in Panel a, Europe in Panel b, and Switzerland in Panel c, SSP5 and SSP1 lie on top of each other, as do SSP2 and SSP4; for medium and low income countries in Panel a; Latin America & and the Caribbean, Asia, and Africa in Panel b; and Nigeria, China, India, and Uganda in Panel c, SSP1, SSP4, and SSP5 lie on top of each other. North America and Australia & New Zealand in Panel b have the same urbanization trend in all SSPs.