Supplementary materials for

Global trends and local variations in land take per person

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Contents

1. Supplementary Methods

To examine the impact of different ways of attributing new built-up land to changes in population and changes in BPC, we tested several options. In the main paper, we decompose the total change in built-up land into changes in population and changes in BPC, so that the multiplication of both equals the total change in built-up land. Here we explain three other methods of attributing changes in built-up land in order to assess the sensitivity for these attributions.

The first alternative is similar to the approach for attributing crop production change to either cropland expansion or yield increase, used for example in Eitelberg et al. (2016) and Wang et al. (2019). This approach could be relevant for SDG target 11.3, which states that the rate of increase in built-up land should not exceed the rate of increase in population, as it effectively takes the BPC in the starting year (BPC_0) of each analysis period as the baseline. Specifically, the area of built-up land change in a given region due to changes in population ($\mathrm{A}_{\mathrm{POP}}$) and due to changes in BPC ($\mathrm{A}_{\mathrm{BPC}}$), respectively, can be calculated as:

$$\mathrm{A}_{\mathrm{POP}} = \mathrm{BPC}_0 \times (\mathrm{POP}_1 - \mathrm{POP}_0) \quad \text{(S1)}$$

$$\mathrm{A}_{\mathrm{BPC}} = \mathrm{POP}_1 \times (\mathrm{BPC}_1 - \mathrm{BPC}_0) \quad \text{(S2)}$$

Conversely, equations S3 and S4 use BPC_1 as a reference level, thereby effectively assuming that increased/decreased population individually consumes the same amount of built-up land in end year of this period:

$$\mathrm{A}_{\mathrm{POP}} = \mathrm{BPC}_1 \times (\mathrm{POP}_1 - \mathrm{POP}_0) \quad \text{(S3)}$$

$$\mathrm{A}_{\mathrm{BPC}} = \mathrm{POP}_0 \times (\mathrm{BPC}_1 - \mathrm{BPC}_0) \quad \text{(S4)}$$

Equations S5 and S6 use a reference level dependent on the direction of population change: increased population individually consumes the same amount of built-up land in end year of this period. In contrast, decreased population individually consumes the same amount of built-up land in starting year of this period.

$$\mathrm{A}_{\mathrm{POP}} = f(\mathrm{BPC}) \times (\mathrm{POP}_1 - \mathrm{POP}_0) \quad \text{(S5)}$$

$$\mathrm{A}_{\mathrm{BPC}} = f(\mathrm{POP}) \times (\mathrm{BPC}_1 - \mathrm{BPC}_0) \quad \text{(S6)}$$

Here, if $\mathrm{POP}_1 - \mathrm{POP}_0 \geq 0$, then $f(\mathrm{BPC}) = \mathrm{BPC}_1$, and $f(\mathrm{POP}) = \mathrm{POP}_0$; Otherwise, $f(\mathrm{BPC}) = \mathrm{BPC}_0$, and $f(\mathrm{POP}) = \mathrm{POP}_1$.

2. Supplementary Figures

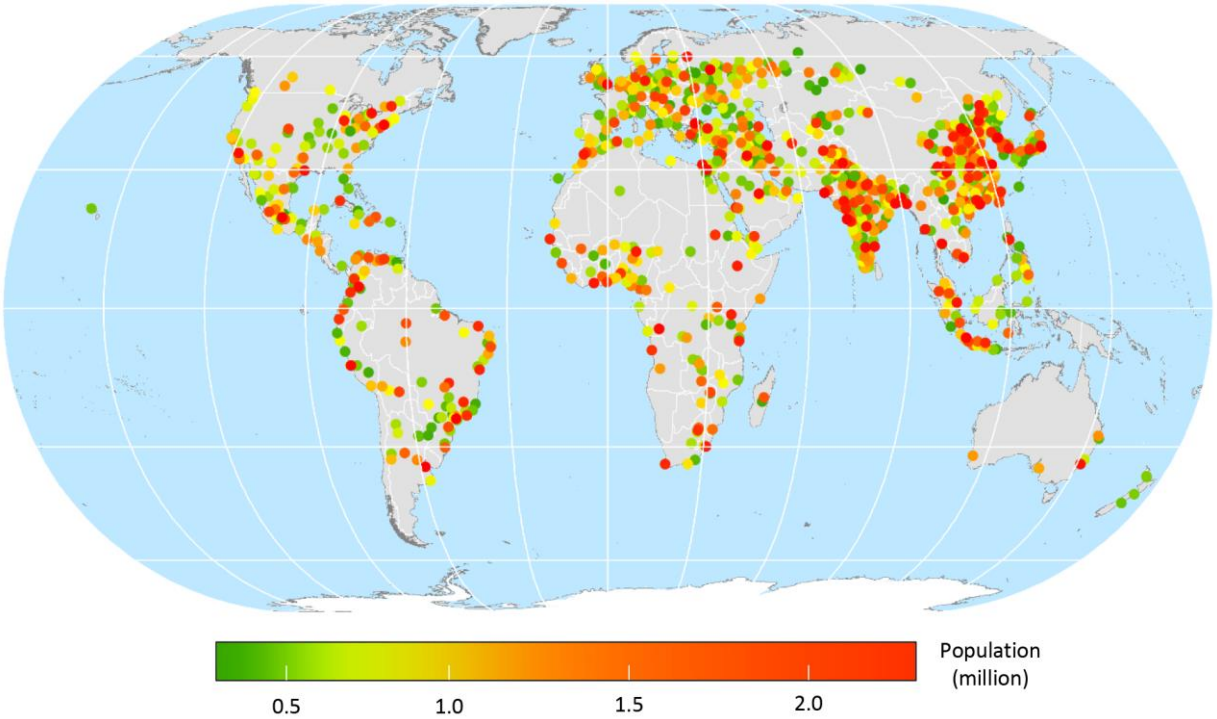

Figure S1. Distribution of cities with a population size large than 0.3 million.

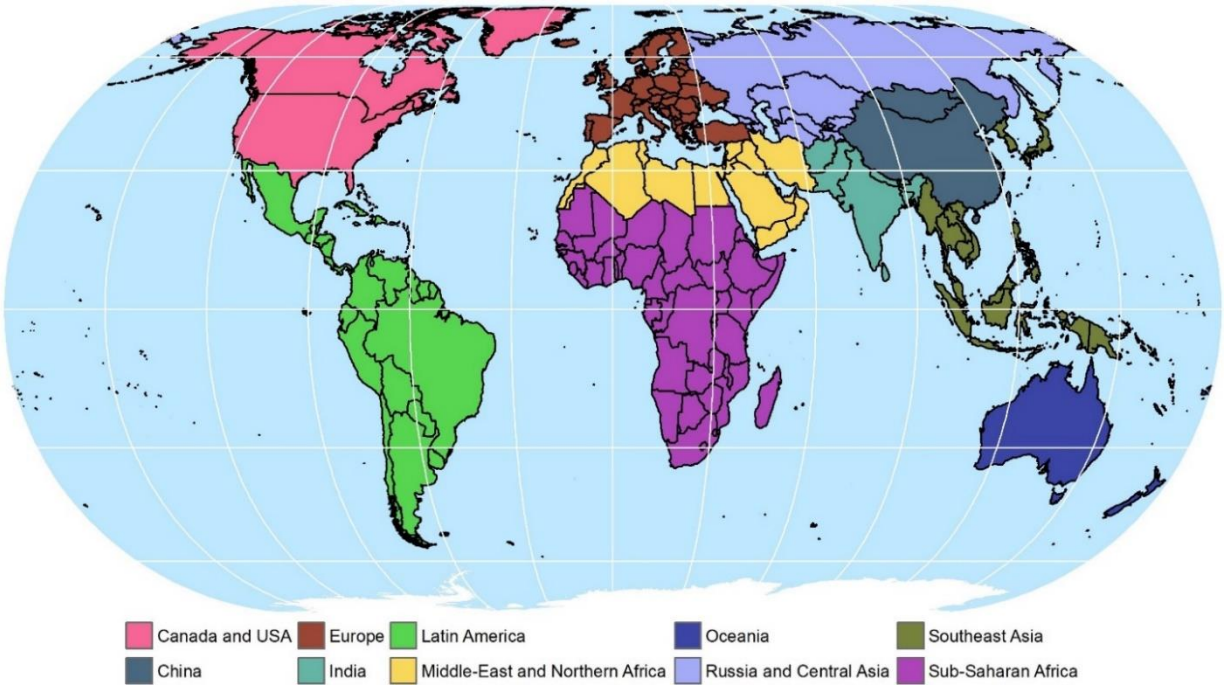

Figure S2. Ten world regions used in this article. Country boundaries are added for further spatial reference.

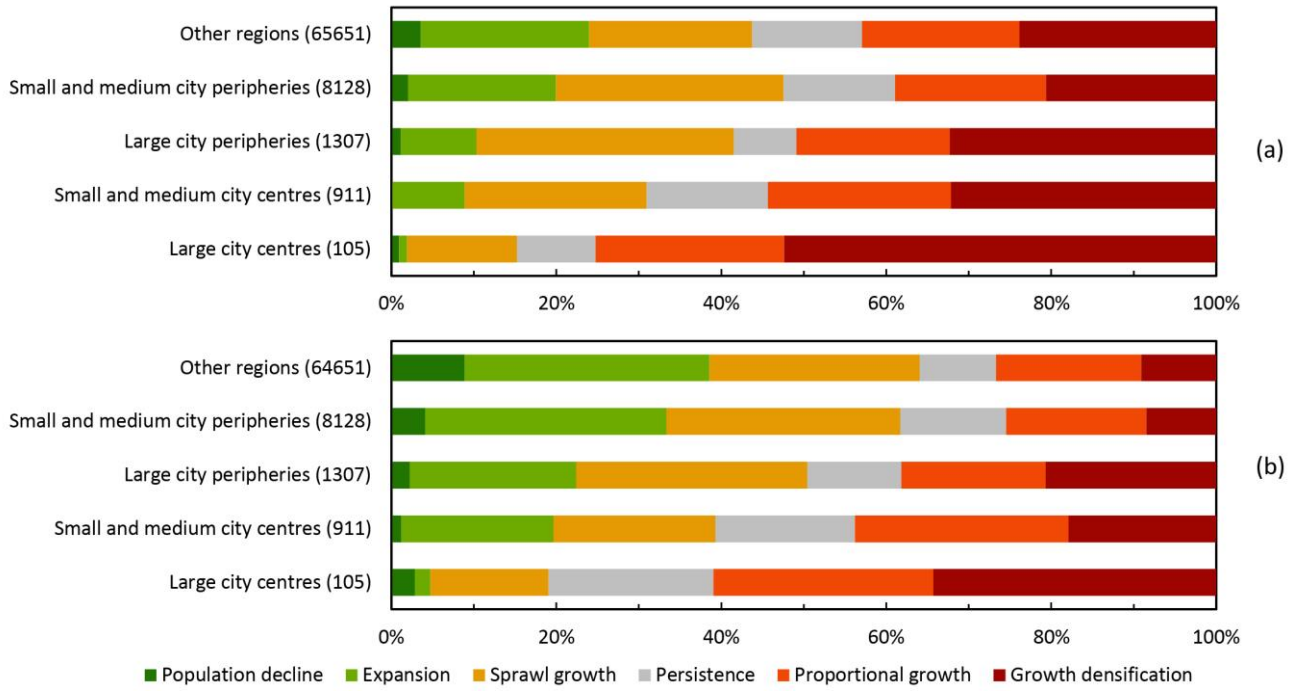

Figure S3. Distribution of built-up land change trajectories over the different types of regions for the periods a) 1975-1990, and b)1990-2000.

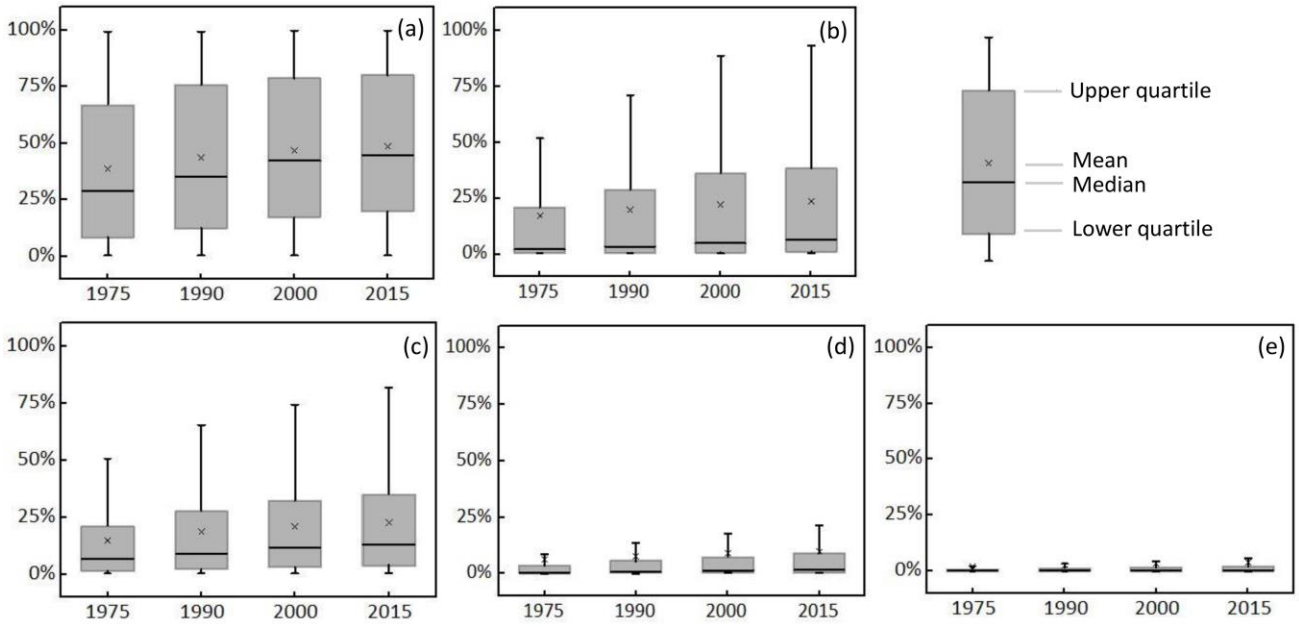

Figure S4. Percentage of built-up land to total available land in each region class. (a) large city centres; (b) large city peripheries; (c) small and medium city centres; (d) small and medium city peripheries; (e) other regions. Each boxplot is based on all regions that are classified as the specific region class, and average are taken over all regions within this class without weighing for their area of amount of built-up land. Calculations are based on the ~38 m GHSL dataset, in which water layers are excluded already.

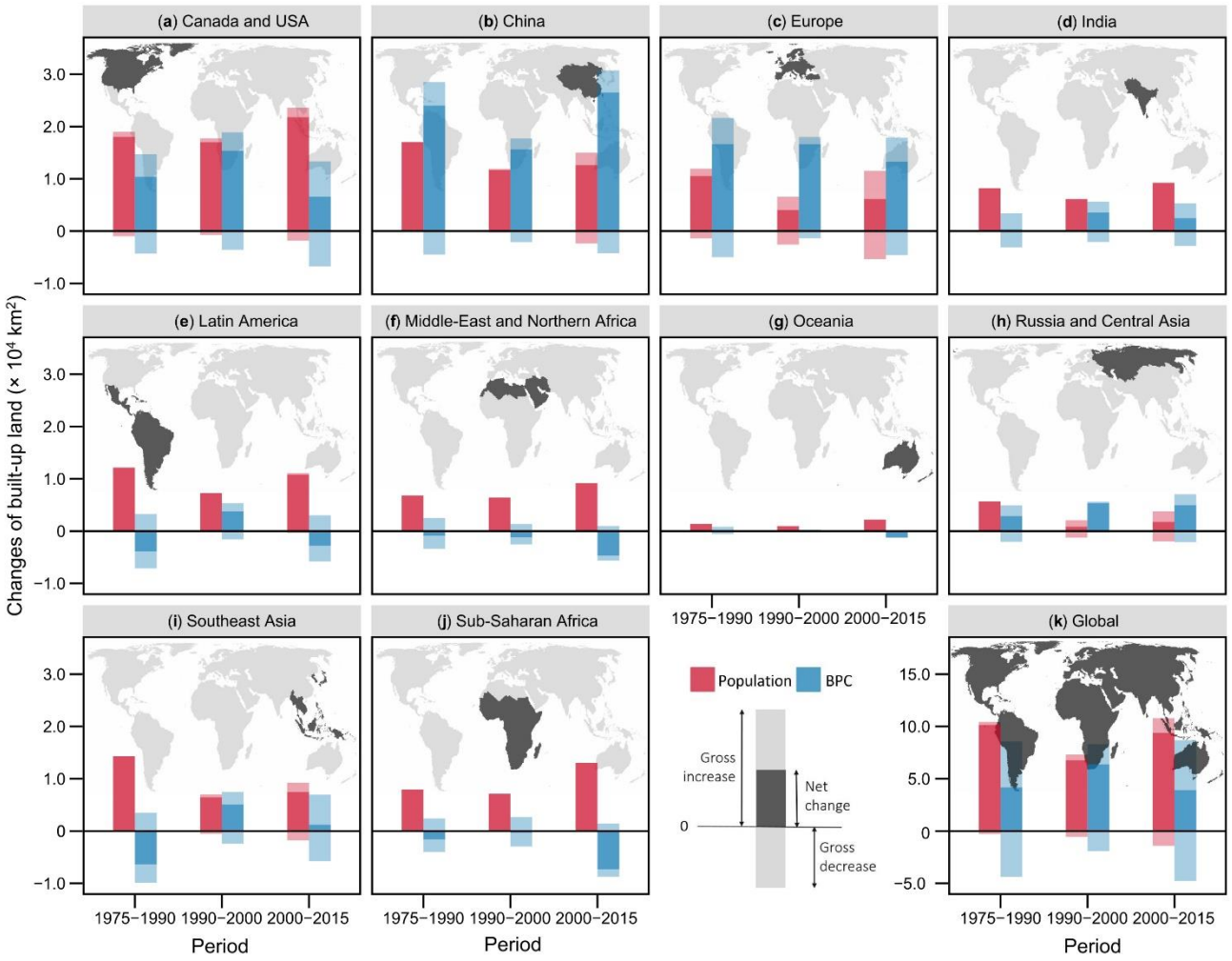

Figure S5. Heterogeneity in built-up land area changes. A_{POP} and A_{BPC} are calculated following equations (S1) and (S2).

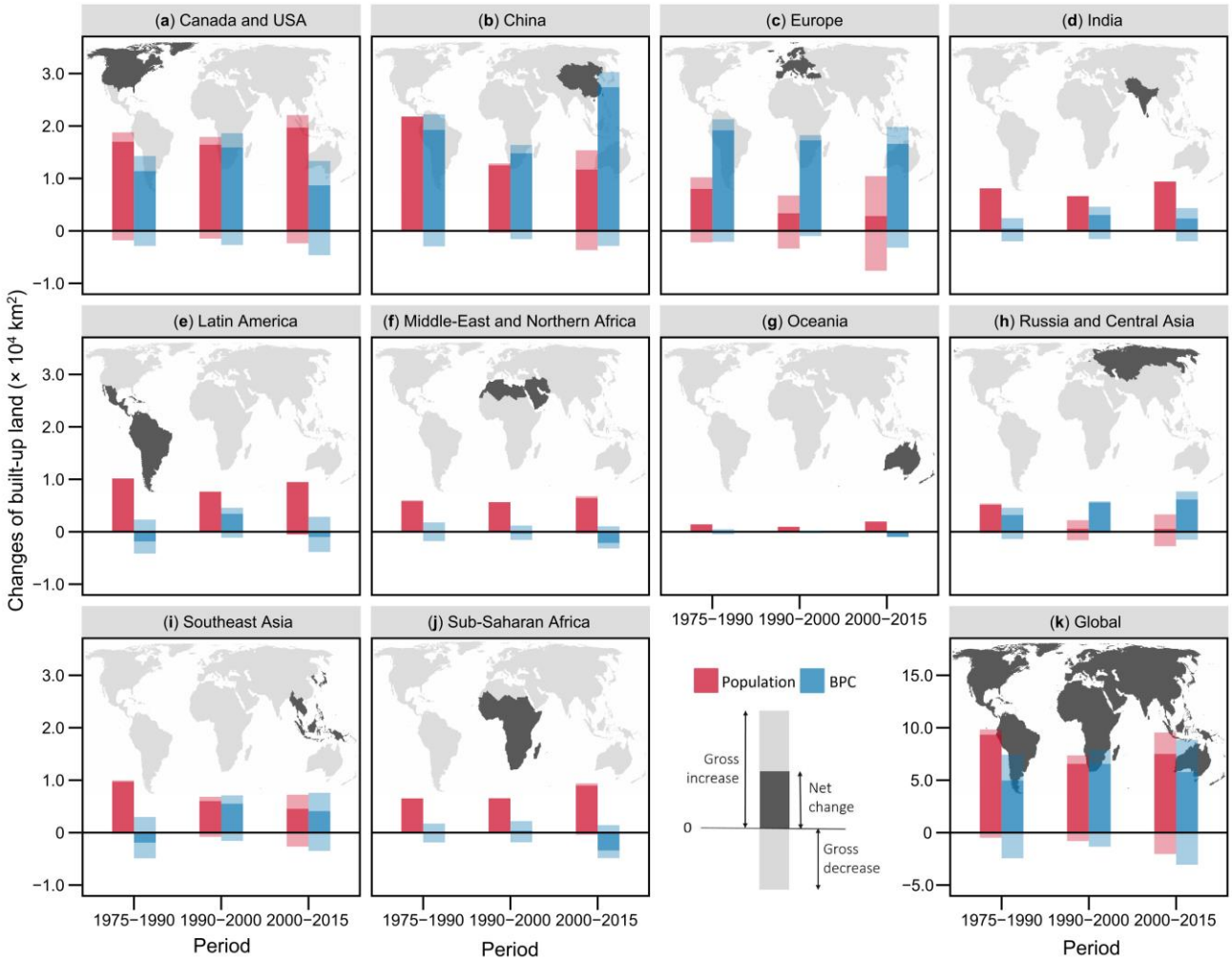

Figure S6. Heterogeneity in built-up land area changes. A_{POP} and A_{BPC} are calculated following equations (S3) and (S4).

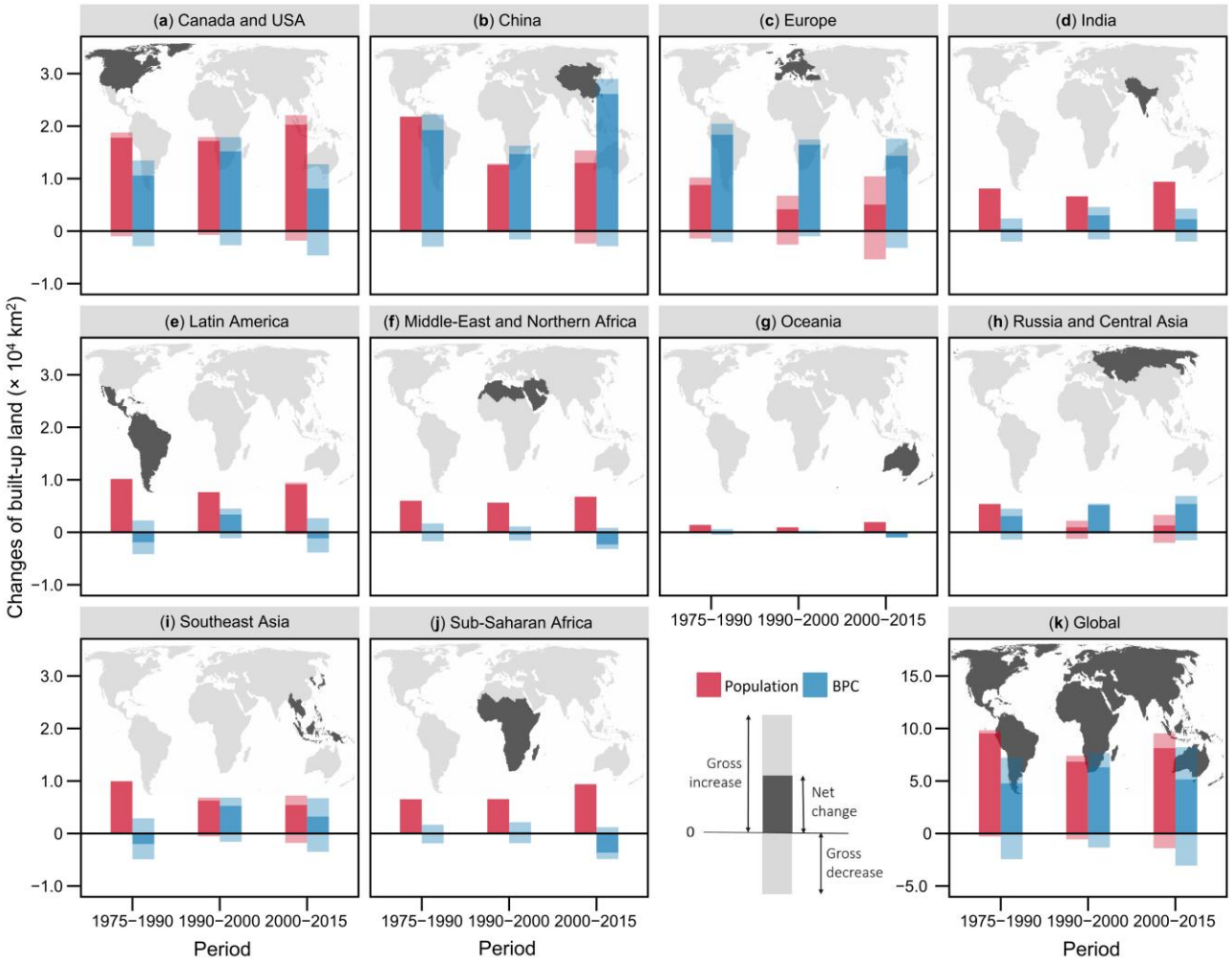

Figure S7. Heterogeneity in built-up land area changes. A_{POP} and A_{BPC} are calculated following equations (S5) and (S6).

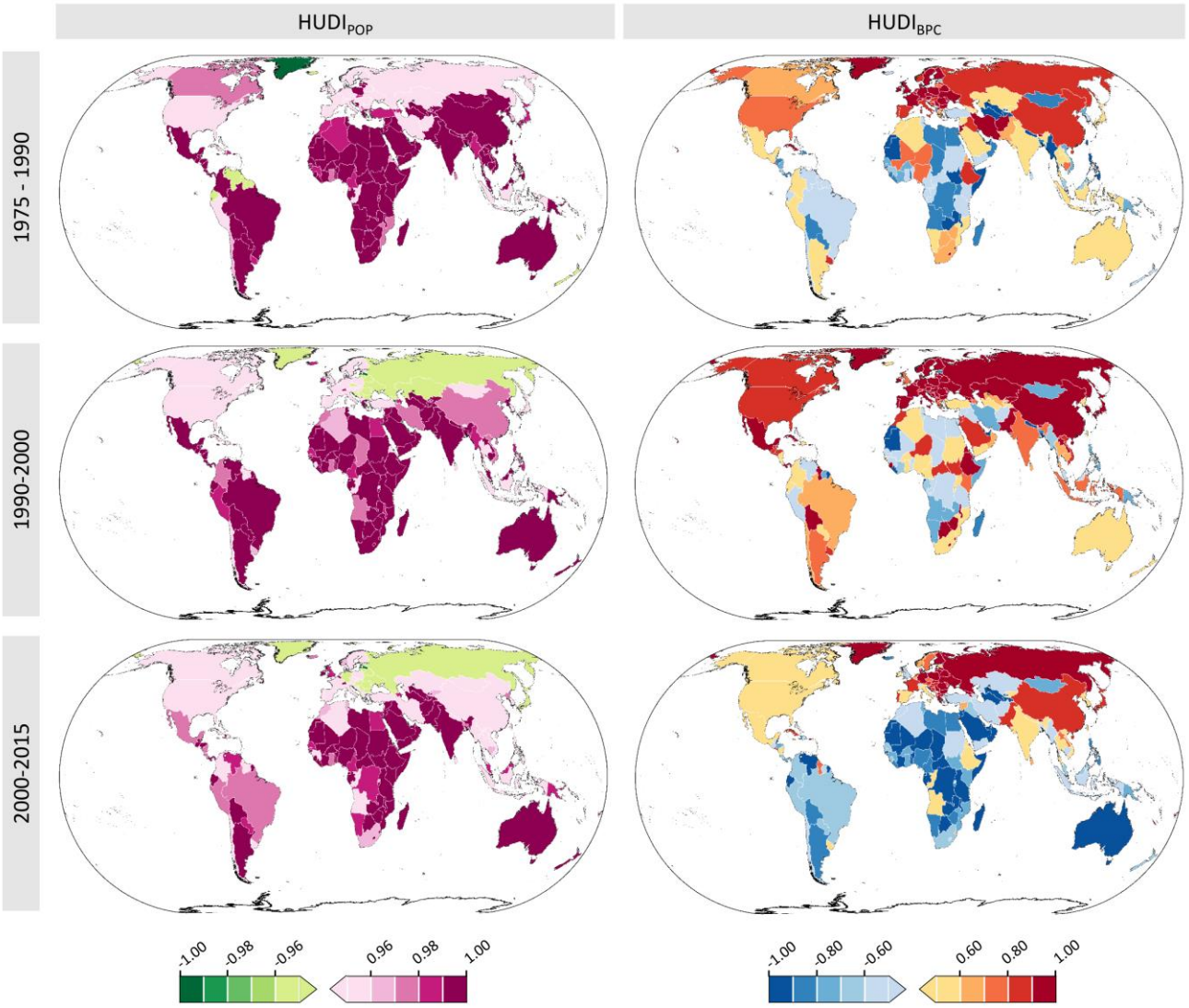

Figure S8. Homogeneity in built-up land change due to changes in population and due to changes in BPC within countries. Values closer to 1 or closer to -1 indicate that regions within a country all develop homogeneously, in terms of population dynamics or BPC changes, while values closer to 0 indicate more heterogeneous developments within a country.

3. Supplementary Tables

Table S1. Analysis units for each country. For a full list of this table, please see the tabular file along with this supplementary material.

ID	Country/Region code	Country/Region name	Most detailed unit available	Mean population per Level-2 unit	Analysis unit
1	ABW	Aruba	Level-0	-	-
2	AFG	Afghanistan	Level-2	-	Level-2
3	AGO	Angola	Level-3	146573	Level-2
4	AIA	Anguilla	Level-0	-	-
5	ALA	Åland	Level-1	-	Level-1
6	ALB	Albania	Level-3	78002	Level-2
7	AND	Andorra	Level-1	-	Level-1
8	ARE	United Arab Emirates	Level-3	42726	Level-2
9	ARG	Argentina	Level-2	-	Level-2
10	ARM	Armenia	Level-1	-	Level-1
11	ASM	American Samoa	Level-3	3281	Level-2
12	ATA	Antarctica	Level-0	-	-
13	ATF	French Southern Territories	Level-1	-	Level-1
14	ATG	Antigua and Barbuda	Level-1	-	Level-1
15	AUS	Australia	Level-2	-	Level-2
16	AUT	Austria	Level-3	78228	Level-2
17	AZE	Azerbaijan	Level-2	-	Level-2
18	BDI	Burundi	Level-4	79857	Level-2
19	BEL	Belgium	Level-4	1025858	Level-3
20	BEN	Benin	Level-2	-	Level-2
21	BES	Bonaire, Sint Eustatius and Saba	Level-1	-	Level-1
22	BFA	Burkina Faso	Level-3	401781	Level-3
23	BGD	Bangladesh	Level-4	2248805	Level-3
24	BGR	Bulgaria	Level-2	-	Level-2
25	BHR	Bahrain	Level-1	-	Level-1
26	BHS	Bahamas	Level-1	-	Level-1
27	BIH	Bosnia and Herzegovina	Level-3	210094	Level-3
28	BLM	Saint-Barthélemy	Level-0	-	-
29	BLR	Belarus	Level-2	-	Level-2
30	BLZ	Belize	Level-1	-	Level-1
31	BMU	Bermuda	Level-1	-	Level-1
32	BOL	Bolivia	Level-3	89685	Level-2
33	BRA	Brazil	Level-3	29478	Level-2
…	…	…	…	…	…
256	ZWE	Zimbabwe	Level-2	-	Level-2

Table S2. Comparison of different approaches to allocating built-up land changes (in thousand km^2) to changes in population and to changes in built-up land area per capita (BPC).

Period	Equations (S1) and (S2)		Equations (S3) and (S4)		Equations (S5) and (S6)		Equations (1) and (2)		Mean		S.D.	
	A_{POP}	A_{BPC}	A_{POP}	A_{BPC}	A_{POP}	A_{BPC}	A_{POP}	A_{BPC}	A_{POP}	A_{BPC}	A_{POP}	A_{BPC}
1975-1990	101.46 (70.9%)	41.70 (29.1%)	93.43 (65.3%)	49.74 (34.7%)	95.46 (66.7%)	47.71 (33.3%)	88.22 (61.7%)	54.77 (38.3%)	94.64 (66.1%)	48.48 (33.9%)	5.48 (3.8%)	5.41 (3.8%)
1990-2000	67.70 (51.5%)	63.87 (48.5%)	65.96 (50.1%)	65.61 (49.9%)	68.43 (52.0%)	63.14 (48.0%)	66.14 (50.4%)	65.21 (49.6%)	67.12 (51.0%)	64.46 (49.0%)	1.15 (0.9%)	1.16 (0.9%)
2000-2015	93.71 (70.5%)	39.13 (29.5%)	74.98 (46.4%)	57.86 (43.6%)	81.33 (61.2%)	51.51 (38.8%)	83.05 (62.5%)	49.58 (37.5%)	83.27 (62.7%)	49.58 (37.3%)	7.78 (5.9%)	7.78 (5.9%)

Table S3. Built-up land and population for major world regions as well as their changes over time. For each world region, 'Sum' refers to the total built-up land area or population in the starting year, or their total changes. Similarly, 'Mean' represents the average built-up land area or population per subdivision in the starting year, or their average changes per subdivision for corresponding world region. As indicated, mean values for nearly all world regions are significantly different from the mean of the entire regions combined (two-tailed t-test, **p<0.01, *p<0.05).

Period	World region	Built-up land in the starting year [km²]		New built-up land [km²]		Population in the starting year [million]		Population change [million]	
		Sum	Mean	Sum	Mean	Sum	Mean	Sum	Mean
1975-1990	Canada and USA	86965	25**	28386	8**	242	0.07**	38	0.01**
	China	47651	17**	41050	15**	939	0.34**	252	0.09**
	Europe	95541	5	27187	1**	580	0.03**	44	0.00**
	India	18411	5	8534	2*	801	0.20**	333	0.08**
	Latin America	27067	2**	8030	1*	330	0.03**	114	0.01**
	Middle-East and Northern Africa	12334	3**	5815	2*	168	0.05**	79	0.02**
	Oceania	6252	8**	1553	2	17	0.02**	4	0.00**
	Russia and Central Asia	27055	9**	8330	3**	184	0.06*	30	0.01**
	Southeast Asia	40095	3**	7792	1**	469	0.04**	148	0.01**
	Sub-Saharan Africa	13694	1**	6311	1**	349	0.03**	172	0.01**
1990-2000	Canada and USA	115351	33**	32380	9**	280	0.08*	35	0.01
	China	88701	32**	27299	10**	1191	0.43**	117	0.04**
	Europe	122728	6**	20631	1**	624	0.03**	16	0.00**
	India	26945	7	9662	2**	1134	0.29**	253	0.06**
	Latin America	35097	3**	10962	1**	444	0.03**	80	0.01**
	Middle-East and Northern Africa	18149	5**	5119	1**	247	0.07	71	0.02**
	Oceania	7805	10**	1034	1	21	0.03**	3	0.00**
	Russia and Central Asia	35386	12**	6158	2*	214	0.07	3	0.00**
	Southeast Asia	47887	4**	11534	1**	617	0.05**	95	0.01**
	Sub-Saharan Africa	20005	2**	6816	1**	521	0.04**	159	0.01**
2000-2015	Canada and USA	147731	42**	28386	8**	315	0.09	41	0.01**
	China	116000	42**	39120	14**	1308	0.47**	99	0.04**
	Europe	143359	7**	19431	1**	640	0.03**	29	0.00**
	India	36607	9	11672	3**	1386	0.35**	354	0.09**
	Latin America	46060	4**	7985	1**	524	0.04**	107	0.01**
	Middle-East and Northern Africa	23268	6**	4269	1**	318	0.09	103	0.03**
	Oceania	8840	11*	1066	1	24	0.03**	6	0.01**
	Russia and Central Asia	41544	14**	6721	2**	217	0.07*	10	0.00**
	Southeast Asia	59420	4**	8649	1**	712	0.05**	118	0.01**
	Sub-Saharan Africa	26821	2**	5559	0**	680	0.06**	319	0.03**

Table S4. BPC and relative changes in built-up land, population, and BPC for ten major world regions. For large parts of the world regions, BPC in the starting year, annual built-up land change, annual population change, and annual BPC change are significantly different from these for all world regions combined (two-tailed t-test, **p<0.01, *p<0.05).

Period	World region	BPC in the starting year [m²/person]	Δ Built-up land	Δ Population	Δ BPC
1975-1990	Canada and USA	359**	1.90%**	0.97%**	0.92%**
	China	51**	4.23%**	1.60%**	2.59%**
	Europe	165**	1.68%**	0.49%**	1.19%**
	India	23**	2.57%**	2.34%**	0.22%**
	Latin America	82**	1.75%**	1.99%	-0.24%**
	Middle-East and Northern Africa	73*	2.61%**	2.59%**	0.01%**
	Oceania	361**	1.49%**	1.29%**	0.19%
	Russia and Central Asia	147	1.81%**	1.00%**	0.80%*
	Southeast Asia	85**	1.19%**	1.84%**	-0.64%**
	Sub-Saharan Africa	39**	2.56%**	2.70%**	-0.14%
1990-2000	Canada and USA	412**	2.51%**	1.20%	1.29%**
	China	74**	2.72%	0.94%**	1.76%**
	Europe	197**	1.57%**	0.25%**	1.31%**
	India	24**	3.11%**	2.03%**	1.06%**
	Latin America	79**	2.76%**	1.66%	1.07%**
	Middle-East and Northern Africa	73**	2.52%**	2.55%**	-0.03%**
	Oceania	371**	1.25%**	1.16%	0.09%**
	Russia and Central Asia	166**	1.62%**	0.15%**	1.46%**
	Southeast Asia	78**	2.18%**	1.44%**	0.73%**
	Sub-Saharan Africa	38**	2.98%**	2.71%**	0.26%**
2000-2015	Canada and USA	469**	1.18%**	0.83%**	0.35%**
	China	89**	1.96%**	0.49%**	1.46%**
	Europe	224**	0.85%**	0.29%**	0.56%**
	India	26**	1.86%**	1.53%**	0.33%**
	Latin America	88**	1.07%	1.24%*	-0.17%
	Middle-East and Northern Africa	73**	1.13%*	1.89%**	-0.75%**
	Oceania	375**	0.76%	1.43%**	-0.66%**
	Russia and Central Asia	192**	1.00%**	0.30%**	0.70%**
	Southeast Asia	83**	0.91%	1.03%**	-0.11%**
	Sub-Saharan Africa	39**	1.26%**	2.60%**	-1.30%**

4. Supplementary References

Eitelberg, D. A., van Vliet, J., Doelman, J. C., Stehfest, E., Verburg, P. H., 2016, Demand for biodiversity protection and carbon storage as drivers of global land change scenarios, *Global Environmental Change* **40:**101-111. https://doi.org/10.1016/j.gloenvcha.2016.06.014

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