

1 Regionalisation of population growth projections in coastal exposure analysis

2 Jan-Ludolf Merkens^{a*}, Daniel Lincke^b, Jochen Hinkel^{b,c}, Sally Brown^{d,e}, Athanasios Thomas Vafeidis^a

3 ^a *Department of Geography, Kiel University, Ludewig-Meyn-Str. 14, 24118 Kiel, Germany*

4 ^b *Global Climate Forum e.V. (GCF), Neue Promenade 6, 10178 Berlin, Germany*

5 ^c *Division of Resource Economics, Albrecht Daniel Thaer-Institute and Berlin Workshop in Institutional Analysis*
6 *of Social-Ecological Systems (WINS), Humboldt-University, Berlin*

7 ^d *Faculty of Engineering and the Environment, University of Southampton, University Rd, Southampton SO17*
8 *1BJ, UK*

9 ^e *Tyndall Centre for Climate Change Research, Southampton, UK*

10 * merkens@geographie.uni-kiel.de; FON +49 431 880-1701; FAX +49 431 880-4658

11

12 Abstract

13 Large-area coastal exposure and impact analysis has focussed on using sea-level rise (SLR) scenarios and has
14 placed little emphasis on socioeconomic scenarios, while neglecting spatial variations of population dynamics. We
15 use the Dynamic Interactive Vulnerability Assessment (DIVA) Framework to assess the population exposed to 1
16 in 100-year coastal flood events under different population scenarios, that are consistent with the Shared
17 Socioeconomic Pathways (SSPs); and different SLR scenarios, derived from the Representative Concentration
18 Pathways (RCPs); and analyse the effect of accounting for regionalised population dynamics on population
19 exposure until 2100. In a reference approach, we use homogeneous population growth on national level. In the
20 regionalisation approaches, we test existing spatially explicit projections that also account for urbanisation, coastal
21 migration and urban sprawl. Our results show that projected global exposure in 2100 ranges from 100 million to
22 260 million, depending on the combination of SLR and population scenarios and method used for regionalising
23 the population projections. The assessed exposure based on the regionalised approaches is higher than that derived
24 from the reference approach by up to 60 million people (39%). Accounting for urbanisation and coastal migration
25 leads to an increase in exposure, whereas considering urban sprawl leads to lower exposure. Differences between
26 the reference and the regionalised approaches increase with higher SLR. The regionalised approaches show highest
27 exposure under SSP5 over most of the 21st century, although total population in SSP5 is the second lowest overall.
28 All methods project the largest absolute growth in exposure for Asia and relative growth for Africa.

29 **Keywords:** sea-level rise, Shared Socioeconomic Pathways, coastal population dynamics, coastal flooding
30 exposure

31 1 Introduction

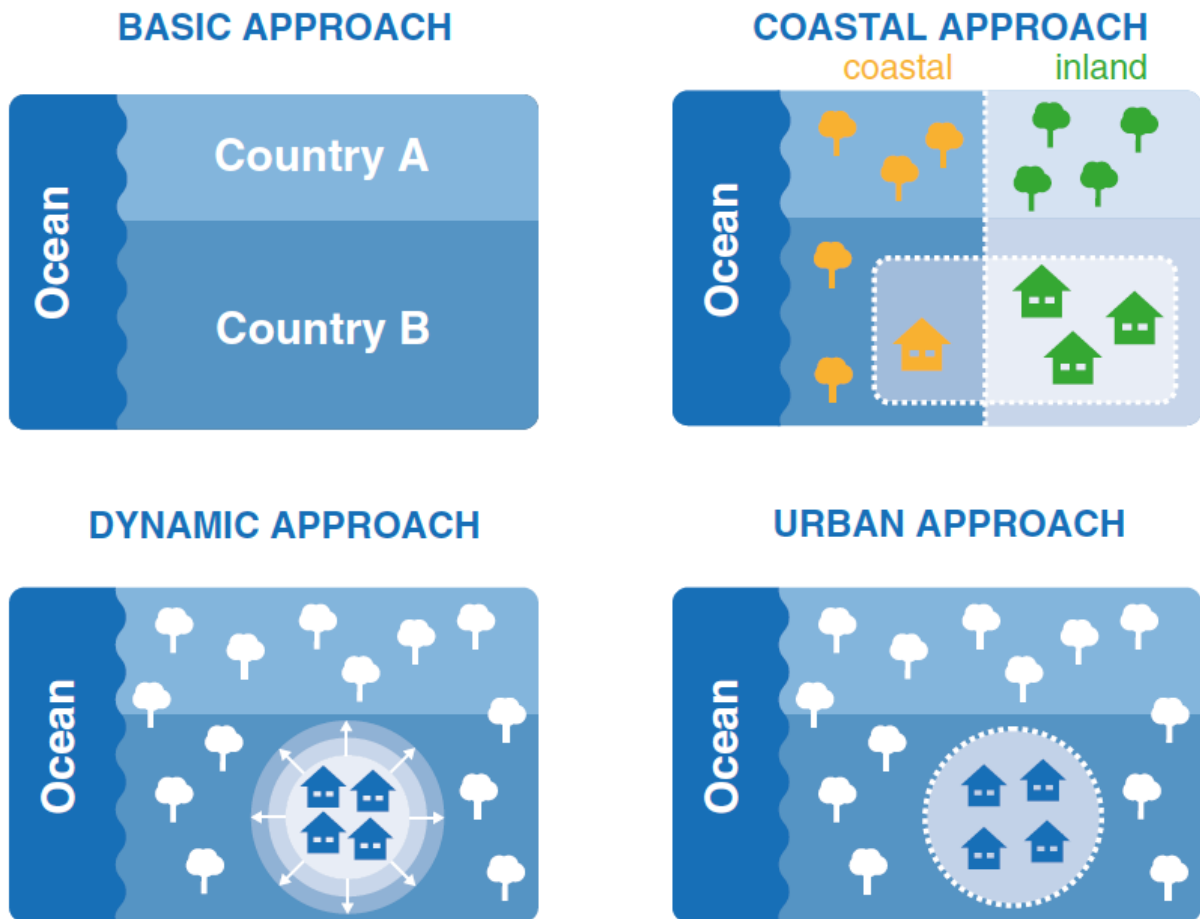
32 A large number of studies have assessed future coastal exposure to sea-level rise (SLR) and respective impacts on
33 global scale (e.g. Hanson et al. 2011; Hallegatte et al. 2013; Neumann et al. 2015). These studies rely on SLR and
34 socio-economic scenarios, because future climate and socio-economic change cannot be forecasted over decades
35 due to deep uncertainties and alternating pathways of development involved. While a lot of emphasis has been
36 placed on developing adequate SLR scenarios that account for uncertainties in future SLR, much less emphasis
37 has been placed on socio-economic scenarios, even though both uncertainties are roughly at equal footing in terms
38 of their influence on future coastal exposure and impacts (Hinkel et al. 2014).

39 The implementation of population changes in global coastal impact assessments has generally improved since the
40 1990s, as at that time studies assumed socioeconomic conditions to remain constant (e.g. Nicholls and Mimura
41 1998) and were therefore unrealistic for future conditions. In recent years multiple scenarios of socioeconomic
42 development on global, continental or national level have been employed in global coastal impact assessment in
43 order to account for uncertainties in socioeconomic development and lead to plausible estimates on future exposure
44 (see e.g. Nicholls (2004) and Arnell et al. (2004) for the Intergovernmental Panel on Climate Change (IPCC)
45 Special Report on Emission Scenarios (SRES) and e.g. Hinkel et al. (2014) for the Shared Socioeconomic
46 Pathways (SSPs)). However, these approaches used population projections on national level and did not account
47 for different population change rates in coastal and inland areas. As coastal zones typically face different
48 challenges compared to inland areas, including differing rates of economic growth and a higher density of cities
49 (McGranahan et al. 2007; Seto 2011; Kummur et al. 2016), coastal population was underestimated.

50 For this reason, some recent studies of global coastal exposure have used higher growth rates for coastal population
51 than for inland population. Nicholls et al. (2008) assumed coastal population to grow up to 2 times faster than the
52 national average. Neumann et al. (2015) refined the approach of Nicholls et al. (2008) and differentiated between
53 coastal and inland population development for urban and non-urban areas by using correction factors. These
54 correction factors allowed coastal population to remain constant if inland population was projected to decrease
55 and grew 1.7 to 2 times faster than the inland population if the inland population was projected to increase. These
56 approaches have the limitations of assuming first, arbitrary correction factors, and second that coastal population
57 develop faster than inland population for all countries, which is, not always the case. Merkens et al. (2016), for
58 example, tested this assumption against historical population data for coastal countries between 1990 and 2000
59 and found that for 40-50% of all countries inland urban and rural locations grow faster than their coastal
60 counterparts.

61 Spatially explicit population projections provide a more realistic basis for coastal exposure analysis. Gaffin et al.
62 (2004) developed population projections until 2100 consistent with the SRES with a horizontal resolution of 15'
63 (~30 km at the equator). Grüber et al. (2007) produced gridded population projections with a horizontal resolution
64 of 7.5' (~15 km at the equator) for three of four SRES scenarios. Their work was refined by Jones and O'Neill
65 (2016), who created gridded population projection for all five SSPs at an initial horizontal resolution of 7.5'. Their
66 projections were downscaled to 0.5' (~ 1km at the equator) by Gao (2017). Jones and O'Neill (2016) analysed
67 historical trends of population development and used a gravity-based downscaling model to simulate urban and
68 rural population changes. For all five SSPs an index of potential attractiveness for each grid cell was used to
69 allocate population, which indirectly leads to different growth rates on subnational level for coastal and inland
70 areas. Merkens et al. (2016) created gridded population projections with a horizontal resolution of 0.5' for all five
71 SSPs that focused on coastal areas and analysed historical growth differences of coastal urban and coastal rural
72 areas compared to the inland counterparts. Their method is described in more detail in section 2.2. In addition,
73 they expanded the qualitative narratives of the SSPs to the coastal zone and assumed scenario-specific
74 modifications of the observed growth differences that are based on the narratives. Both studies, Jones and O'Neill
75 (2016) and Merkens et al. (2016), are consistent with the population projections (KC and Lutz 2017) and
76 urbanisation projections (Jiang and O'Neill 2017) on national level that are used in the SSP framework (O'Neill
77 et al. 2017).

78 In this study we assess the sensitivity of outcomes in coastal exposure analysis to inclusion of subnational
79 heterogeneity in population projections. We compare (i) homogeneous population change on national level
80 (hereinafter referred to as the basic approach) to (ii) the population projections of Merkens et al. (2016) that also
81 account for urbanisation and coastal migration are have been specifically developed for coastal exposure analysis
82 (hereinafter referred to as the coastal approach) and to (iii) the downscaled spatial projections of Jones and O'Neill
83 (2016) by Gao (2017) that account for urbanisation and urban sprawl (referred to as dynamic approach)). We
84 further analyse (iv) the extent to which urbanisation can explain the differences in exposure between the basic and
85 coastal approach (referred to as urban approach) (see Fig. 1).



86

87 *Fig. 1: Regionalisation approaches. The basic approach assumes homogeneous population dynamics within a country. The*
 88 *coastal approach differentiates population dynamics between coastal urban, coastal rural, inland urban and inland rural*
 89 *areas. The dynamic approach uses dynamic urban extents to account for urban sprawl. The urban approach differentiates*
 90 *urban and rural population dynamics with static urban extents*

91 **2 Data and Methods**

92 **2.1 DIVA database**

93 For our analysis, we employ the Dynamic Interactive Vulnerability Assessment (DIVA) modelling framework,
 94 which has been used in a wide range of applications in coastal risk assessments (see Hinkel et al. 2013 for erosion,
 95 Hinkel et al. 2010 and Hinkel et al. 2014 for adaptation, Hinkel et al. 2012 for adaptation and mitigation, Spencer
 96 et al. 2016 for wetlands). The results presented in this study are based on version 30 of the DIVA database and
 97 model version 1.7.

98 The DIVA database breaks the world's coasts (excluding Antarctica) into 12,148 segments. Each coastal segment
 99 provides information on administrative, bio-physical and socioecological attributes. In the context of this study,
 100 we focus on the population living in the 1 in 100-year floodplain, which is a well-established measure of coastal
 101 exposure analysis (e.g. Hanson et al. 2011; Vousdoukas et al. 2016; Muis et al. 2017). The 1 in 100-year coastal
 102 flood heights are taken from Muis et al. (2016). We use the DIVA flood module to calculate the number of people

103 living in the floodplain without considering dikes. A detailed description of this approach can be found in Hinkel
104 et al. (2014). As we account for isostatic adjustment and subsidence (see section 2.3), DIVA provides relative sea-
105 level for all segments.

106 To define the floodplain, we use a global elevation dataset which is based on SRTM (Jarvis et al. 2008) and
107 GTOPO30 (USGS 1996) data for high latitudes ($>60^{\circ}\text{N}$ and $>54^{\circ}\text{S}$). For all elevation steps from 1m to 16m, we
108 calculate the extent of the area that is hydrologically connected to the ocean and smaller or equal to the respective
109 elevation threshold (see Poulter and Halpin 2008). Intermediate values are linearly interpolated (Hinkel et al.
110 2014). We utilise the GRUMPv1 grid (CIESIN et al. 2011a) to analyse the population located in each of these
111 elevation increments for the year 2000. The coastal SSPs of Merkens et al. (2016) use the GRUMP urban extent
112 grid, which uses census population counts, settlement points and night-time lights, to define urban areas (CIESIN
113 et al. 2011b) and assumes these to be static. GRUMP tends to underestimate the extent of settlements with
114 none or little light at night, e.g. in parts of Africa (Balk et al. 2006), which also affects the estimates on exposed
115 population. The estimates on exposed population also depend on the elevation model used for the analysis. Lichter
116 et al. (2011) analysed the land area of the LECZ derived from three different elevation datasets with the same
117 vertical and horizontal resolution of 1m and 0.5' ($\sim 1\text{km}$ at the equator). On continental scale, they found
118 differences of up to 40%. In the same study, Lichter et al. (2011) compared two commonly used population datasets
119 (GRUMP alpha and LandScan 2006) and analysed the population located in the LECZ. On global scale, the LECZ
120 population differed by $\sim 10\%$, on continental scale by up to 28%. They stated the combined uncertainty of elevation
121 and population data at 20% on global scale and at up to 67% on continental scale. Mondal and Tatem (2012)
122 compared the LECZ population for GRUMP version 1 (the same version that was used in this study) and LandScan
123 2008 and found differences of 4% on global scale and of up to 39% on continental scale. GRUMP's underlying
124 assumption of homogeneous population distribution within urban and rural areas in the same administrative unit
125 can in addition lead to an over- or underestimation of the 'true' exposure (Merkens and Vafeidis 2018). As this
126 study uses the same population and elevation datasets throughout the analysis, we expect the relative differences
127 between the approaches to be independent from the elevation or population data, whereas the absolute numbers
128 are likely to be different if other population or elevation data are used.

129 2.2 Socioeconomic scenarios

130 We initially calculate exposure of population based on two approaches to account for future population
131 development in coastal areas (see Fig. 1). In the basic approach, we use national population projections taken from
132 KC and Lutz (2017) and apply these to the baseline (i.e., year 2000) spatial population data. This approach assumes

133 homogeneous growth rates within each country, i.e. population in coastal areas grows at the same rate than in
134 inland areas. In the coastal approach, we use the coastal SSPs of Merkens et al. (2016). These are based on the
135 national population projections of KC and Lutz (2017) as well, but consider urbanisation projections (Jiang and
136 O’Neill 2017), historical growth differences and scenario-dependent modifications of growth differences. For each
137 country Merkens et al (2016) analysed the population growth for coastal urban (rural) areas and inland urban
138 (rural) areas over a 10-year period from 1990 to 2000. If coastal areas had a higher population growth rate than
139 inland areas, the growth difference (GD) was positive and vice versa. The GD allows for negative (positive)
140 population growth in the coast or inland even if national population growth is positive (negative). It also allows
141 for higher population change rates in coastal areas compared to inland areas. For SSP2 Merkens et al. (2016)
142 assumed the GD to keep constant over time for each location. For the other four SSPs they modified the GDs based
143 on the interpretation of the coastal SSP narratives, which are introduced in the same study. They quantified the
144 modification of the GDs based on the difference between percentiles in the distribution of the observed urban and
145 rural GDs for all coastal countries. In SSP1 they assume no differences in growth for coastal and inland urban
146 areas and a reduced rural GD (translates to relatively higher rural growth in inland). In SSP3 they assume that the
147 GD to reduce by 50% for both, urban and rural areas. In SSP4 and SSP5 they increased the GD (translates to
148 relatively higher relative growth at the coast), whereby the increase was bigger in SSP5. Based on the scenario
149 specific GDs and the population and urbanisation projections they calculated population counts for coastal urban,
150 coastal rural, inland urban and inland rural for each country in 5 year increments until 2100. This leads to
151 heterogeneous growth rates within countries because urban areas develop differently to rural areas and coastal
152 areas differently to inland areas. We then calculate the mean coastal population growth rate for each country and
153 apply it on each coastline segment of this country. We must note that the definitions of ‘urban’ between GRUMP
154 (used in Merkens et al. (2016) and Gao (2017)) and Jiang and O’Neill (2016) differ, which results in an offset in
155 the data for the years 2005 and 2010 (see section 4 for a discussion of the implications on exposure analysis).

156 2.3 Sea-level rise scenarios

157 We use the projected changes in global mean sea level and the likely ranges reported in the Fifth Assessment
158 Report of the Intergovernmental Panel on Climate Change (Church et al. 2013). For each of the four RCPs, we use
159 the ensemble median as medium SLR scenario. The 83rd percentile serves as high SLR scenario and the 17th
160 percentile as low SLR scenario (see Table 1). We do not consider regional patterns of SLR due to ocean dynamics
161 and regionally differential changes in thermal expansion and rotational and gravitational effects of the mass loss
162 of ice sheet. Church et al. (2013) show that these regional effects are below 10% for most of the populated coastal
163 zone with the exception of the East Coast of the US. Hence the global effects of these regional SLR variations are

164 expected to be much smaller than those of human-induced subsidence in densely populated river deltas, which we
 165 consider here together with isostatic adjustment. Furthermore, uncertainties in regional sea level projections are
 166 large, with different models producing different patterns and the highest deviations of regional sea-level rise due
 167 to dynamic variability coinciding with those regions for which model uncertainties are largest (Church et al., 2013).
 168 We assume that water levels during coastal floods increase by the same amount as the projected global sea-level
 169 and do not account for non-linear interactions between the water level and SLR (Arns et al. 2017) as the focus of
 170 this paper is the comparison of population distribution approaches.

171 *Table 1: Sea level rise projections for 2100 referenced to the 1986-2005 period [in m].*

	low	medium	high
RCP2.6	0.28	0.44	0.61
RCP4.5	0.36	0.53	0.71
RCP6.0	0.38	0.55	0.73
RCP8.5	0.53	0.74	0.98

Values are taken from Prather et al. (2014).

172

173 In this study, we use the 12 SLR scenarios from Table 1 (four RCPs, for each high, medium and low SLR
 174 projections). These are combined with the five SSPs. Taking into account the two regionalisation approaches (plus
 175 another two for testing our assumption) in each SSP, we end up with 240 model runs. This number could be
 176 reduced by ignoring scenario combinations that are not plausible. For example, the combination of an
 177 environmentally friendly socioeconomic scenario (SSP1) and a physical scenario with high radiative forcing
 178 (RCP8.5) would in general be inconsistent (van Vuuren et al. 2014; Engström et al. 2016). Nevertheless, we
 179 decided to analyse all scenario combinations, as this study aims to analyse and understand the effect that
 180 regionalisation approaches of socioeconomic scenarios have for impact assessment.

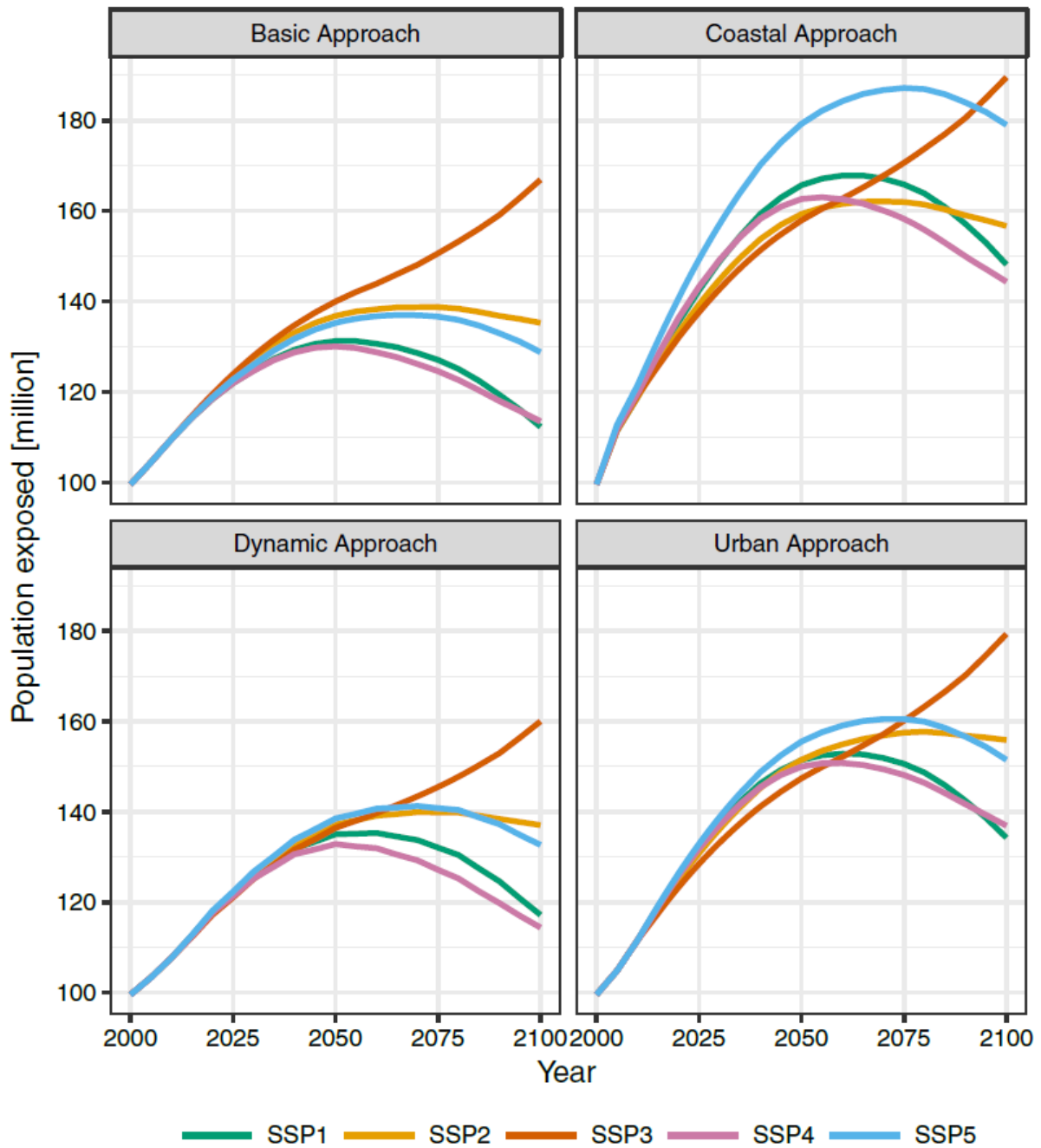
181 3 Results

182 We compare future coastal exposure to 1 in 100-year coastal floods based on the different regionalisation
 183 approaches. We define the absolute difference in exposure as the difference in the tested approach (i.e. coastal,
 184 urban or dynamic) minus the exposure in the basic approach. The relative difference is defined as the absolute
 185 difference in exposure divided by the exposure in the basic approach.

186 3.1 Global

187 Our first main finding is that accounting for urbanisation and coastal migration has significant implications for
 188 assessing coastal exposure. The exposure based on the coastal approach exceeds the one based on the basic
 189 approach in all scenarios over the 21st century (see Fig. 2). This finding is consistent for all SLR scenarios (see

190 Fig. A. 3). For SSP1, 4 and 5 we find the exposure in the basic approach with high SLR in all RCPs to be lower
191 than the respective low SLR variant in the coastal approach. In other words, in these scenarios the difference
192 between the population distribution approaches is larger than the difference between high and low SLR. To
193 investigate which of the two (urbanisation and coastal migration) is the dominant process leading to the difference
194 between basic and coastal approach, we added the ‘urban approach’ to our modelling scheme (see Fig. 1). The
195 urban approach is based on population and urbanisation projections that are modelled in the same way as in the
196 coastal SSPs, but uses a GD of zero, which means that the population in urban and rural zones for each SSP grows
197 at rates consistent with projections on national level and does not differ between coastal and inland areas. We
198 assume that the difference between the urban approach and the basic approach represents the impact of changing
199 urbanisation levels, without considering urban sprawl. The difference between the urban approach and the coastal
200 approach can result from differences in fertility, mortality, international migration or internal migration, of which
201 we assume internal migration from or to the coast to have the highest impact. We find that, independently of SLR,
202 urbanisation explains 61% of the difference between the coastal and basic approach in SSP1, 96% in SSP2, 54%
203 in SSP3, 76% in SSP4 and 45% in SSP5 (see Fig A. 2). This means that SSP5 is the only scenario where
204 urbanisation appears not to be the dominant process. This can be explained by the underlying assumptions of
205 intense coastward migration for SSP5 in the coastal approach (Merkens et al., 2016). In general, the projected
206 increase in urbanisation levels leads to higher population growth rates in the coastal zone compared to inland areas,
207 as coastal areas show a higher density of cities than inland areas, and population is projected to move into these
208 cities. In the basic approach, the population in all areas within a country grows at the same rate, which leads to
209 lower population numbers at the coast compared to the coastal approach. We therefore conclude that the higher
210 exposure in the coastal approach compared to the basic approach is due to a combination of increasing urbanisation
211 levels in all SSPs and migration to coastal areas, of which urbanisation is the dominant process for SSPs 1-4 and
212 coastal migration for SSP5.



213

214 *Fig. 2: Exposure of population to 1 in 100-year coastal floods under medium SLR in RCP6.0 in the tested approaches.*

215 Our second main finding is that the implementation of urban sprawl has a considerable impact on the estimates on
 216 exposure. We compare the urban approach to a ‘dynamic approach’, which is based on the population projections
 217 of Jones and O’Neill (2016) that were downscaled by Gao (2017). Unlike the urban (and coastal) approach, that
 218 assume urban extent to be static, the dynamic approach considers urban sprawl, which leads to wider city extents
 219 and lower population densities within cities. We assume that differences between the urban and dynamic approach
 220 are mainly due to urban sprawl, as the approaches use the same population projections of KC and Lutz (2017) and
 221 the same urbanisation projections of Jiang and O’Neill (2017). Compared to the dynamic approach, we find
 222 exposure to 1 in 100-year coastal floods to be higher in the urban approach for all combinations of SSPs and RCPs

223 (Fig. A. 3). They differ between 15 million in SSP1 (RCP 2.6 and low SLR) and 26 million in SSP4 (RCP 8.5 and
224 high SLR). Differences in SSP1 are lowest, as cities in the dynamic approach are assumed to be concentrated
225 (Jones and O'Neill 2016) and urban extents to be static in the urban (and coastal) approach. However, the
226 difference of 15 million in SSP1 is considerable and suggests that the definition of urban areas (and population)
227 between the urban and the dynamic approach differs, as urbanisation levels and total population do not differ and
228 cities are assumed to be concentrated (dynamic approach) or static (urban approach). For SSPs 2-5 differences
229 between the urban approach and dynamic approach are higher, as only the dynamic approach considers urban
230 sprawl. This suggests that urban sprawl can lead to a reduction of exposure as cities seem to expand towards less
231 flood-prone areas. The differences between the basic and the dynamic approach are rather small (Fig. 2). Global
232 exposure in the dynamic approach under SSP3 for 2100 is up to 7.5 million lower than one in the basic approach.
233 In the other SSPs, exposure based on the dynamic approach exceeds the basic approach by 1 million in SSP4, 2
234 million in SSP2, 5 million in SSP5 and 6 million in SSP1 (see Fig. A. 4). These SSPs are also projected to have a
235 high increase in urbanisation levels, whereas urbanisation levels in SSP3 are projected to increase little (Jiang and
236 O'Neill 2017). This supports our first finding that neglecting urbanisation patterns would lead to an
237 underestimation of coastal exposure. The differences between the dynamic and the coastal approach are larger than
238 the differences between the dynamic and the urban approach (between 17 million in SSP2 under RCP 2.6 with low
239 SLR and 54 million in SSP5 under RCP 8.5 and high SLR), as coastal migration is additionally considered in the
240 coastal approach. Overall we believe that the coastal approach overestimates exposure, as it does not consider
241 urban sprawl, which appears to reduce exposure; and that the dynamic approach underestimates exposure, as it
242 does not explicitly consider coastal migration, which appears to increase exposure to coastal flooding. We must
243 note that this study does not aim to test the underlying quantifications on coastal migration in Merkens et al. (2016)
244 and the quantification of urban sprawl in Jones and O'Neill (2016), but rather to investigate the implications for
245 coastal exposure analysis when accounting or neglecting of processes actually taking place in coastal areas.

246 We also find that the population distribution approach is important in determining which SSP leads to the highest
247 exposure to coastal flooding. Though all approaches agree on SSP3 having the highest exposure in 2100, only the
248 basic approach shows SSP3 to lead to the highest exposure throughout the century. The other approaches agree on
249 SSP5 leading to the highest exposure until 2060 (dynamic approach), 2075 (urban approach) and 2090 (coastal
250 approach) (see Fig. 2). This holds true for all SLR scenarios. This is noteworthy as SSP5 and SSP1 are projected
251 to have considerably lower total populations than the other SSPs (KC and Lutz 2017). We identify two factors
252 leading to this observation. The behaviour in the basic approach can be explained by the underlying global
253 population projections that project population to be highest in SSP3 (KC and Lutz 2017). The higher exposure in

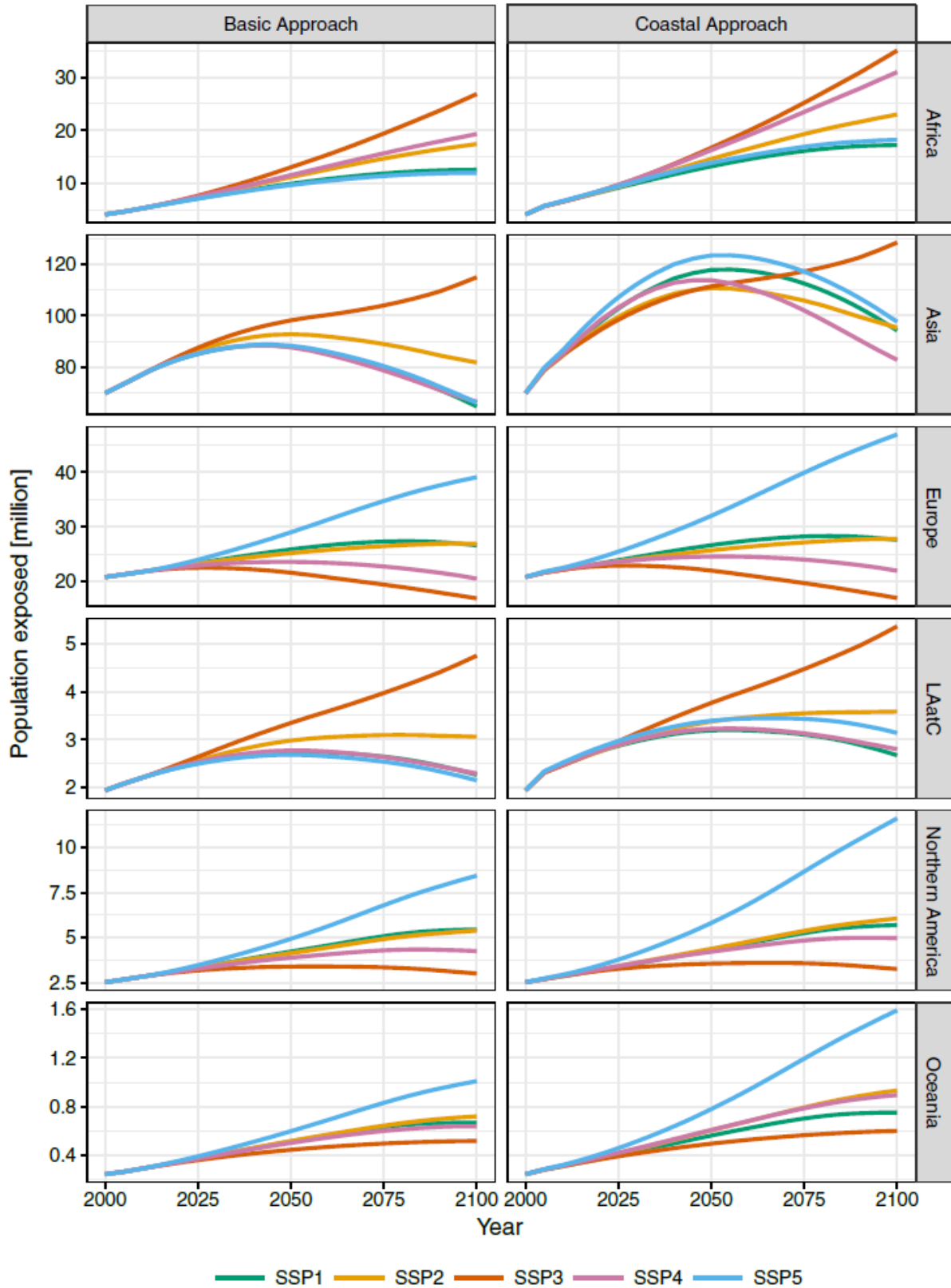
254 SSP5 in the other approaches is due to high urbanisation levels (Jiang and O'Neill 2017). Exposure rises in the
255 coastal approach as coastal areas are assumed to be more attractive than inland areas and decreases in the dynamic
256 approach as high urban sprawl leads to cities expanding to flood proof areas.

257 Results also show that the absolute difference in exposed population between the basic and the other approaches
258 increases with SLR (see Fig. A. 4). We find the highest differences under the high SLR projections in RCP8.5 and
259 the smallest differences under the low SLR projections in RCP2.6. Compared to the basic approach, SSP1, SSP4
260 and SSP5 show the highest difference and SSP2 and SSP3 the lowest. Different to the urban and the coastal
261 approach, the dynamic approach shows a reduced exposure for SSP3 and a higher difference for SSP2 than for
262 SSP4 for 2090 to 2100, when the basic approach is used as reference. Again, this observation highlights the
263 significance of urbanisation, coastal migration and urban sprawl.. As cities are concentrated in coastal areas, the
264 overall population growth in coastal areas is higher than the national average (represented by the basic approach).

265 3.2 Regional

266 In this section we focus on the comparison between the basic and the coastal approach, as the coastal approach
267 explicitly considers coastal migration. Results for the dynamic and urban approach on regional level can be found
268 in the SM.

269 Different to the global patterns, Europe, Northern America and Oceania face the highest exposure under SSP5 for
270 both coastal and basic SSPs (Fig. 3). Exposure increases continuously until 2100 under this SSP. For Africa and
271 Latin America and the Caribbean (LAatC), SSP3 shows the highest exposure throughout the century, which also
272 increases continuously with time. This is in line with the underlying national projections of KC and Lutz (2017)
273 that project highest population under SSP5 for the most developed countries and under SSP3 for developing
274 countries. For Asia, we find a notable difference between the coastal and basic approach. In the basic approach,
275 exposure is highest under SSP3 throughout the 21st century. In the coastal approach, exposure is highest under
276 SSP5 until 2075 and under SSP3 afterwards. Asia's high exposure under SSP5 in the coastal approach reflects the
277 high increase of urbanisation levels in the underlying urbanisation projections (Jiang and O'Neill 2017) and the
278 coastward migration in the coastal SSPs. The decrease in Asia's exposure projected after 2050 is due to the
279 decreasing population after 2050 in the underlying population projections (KC and Lutz 2017). This also can also
280 be seen in the basic approach and holds true for all SSPs except SSP3, where the Asia's population is projected to
281 grow after 2050.



282

283 *Fig. 3: Exposure per continent under medium SLR in RCP6.0. In the basic approach, SSP1 and SSP5 overlap for Africa and*
 284 *Asia. For LAaTC (Latin America and the Caribbean), SSP1 and SSP4 overlap in both approaches.*

285 The absolute difference in exposure to 1 in 100-year coastal floods on continental scale follows global patterns
 286 and becomes larger with SLR in all SSPs (see Fig. A. 7). Accordingly, we find the highest differences in RCP8.5

287 with high SLR and the smallest differences in RCP2.6 with low SLR. The difference between the coastal and basic
288 approach is highest in SSP5 in all continents except Africa, where SSP4 shows the highest differences. We observe
289 the lowest differences in SSP1 for Africa, LAatC, Northern America and Oceania. For Europe and Asia, we find
290 the lowest differences between the coastal and basic approach in SSP3.

291 The relative difference in exposed population is heterogeneous and does not follow the global patterns. For Africa,
292 which shows overall the highest values, we find the relative difference to decrease with rising sea levels (see Table
293 A. 1). The highest difference in exposure is in SSP4 (coastal approach is up to 64% higher than the basic approach)
294 and lowest in SSP2 and SSP3 (coastal approach 24% higher than basic approach). For Asia, we find the highest
295 relative differences between coastal and basic approach in SSP5 (48%) and the lowest in SSP3 (~12%). For
296 Europe, which shows overall the closest agreement between coastal and basic approach, the relative difference in
297 exposure increases slightly with SLR. SSP5 exhibits the highest relative difference in exposure (~20%) and SSP3
298 the lowest (<1%). For Northern America, the relative difference in exposure increases with SLR in SSP1 and
299 decreases in SSP2-5 while the opposite is the case in Asia. For LAatC and Oceania we do not find a relation
300 between SLR and relative difference in exposure based on the basic and coastal SSPs.

301 4 Discussion

302 One of our key findings is that under all scenarios the coastal approach projects higher population located in the
303 floodplain of 1 in 100-year coastal floods than the basic approach. In agreement with previous studies that
304 identified urbanisation as a key component in coastal population development, we explain most of the differences
305 with the projected growing urbanisation levels in the coastal approach (see Fig. A. 1 and Fig. A. 2). Coastal areas
306 today show a higher concentration of cities than inland areas. Kummu et al. (2016) shows that 105 out of 256 cities
307 with a population of more than 1 million are located in the near coast zone (proximity to coast < 100 km and
308 altitude < 100 m). According to Brown et al. (2013), in 2010 20 out of 31 megacities (cities with more than 8
309 million inhabitants) were located in the low-elevation coastal zone (LECZ; altitude \leq 10 m and hydrological
310 connection to the ocean). Neumann et al. (2015) assume that the number of megacities in the LECZ will increase
311 to 25 until 2025. Hoornweg and Pope (2016) project the population development of the 101 largest cities under
312 three SSPs. They show that the percentage of population living in these cities will increase from 11% in 2010 to
313 15% in SSP3, 20% in SSP2 and 23% in SSP1 until 2100. As the coastal approach accounts for urbanisation
314 (Merkens et al. 2016) and the basic approach does not, coastal population tends to be underestimated in the basic
315 approach.

316 The basic approach shows similar results to the study of Jongman et al. (2012) that also used a homogeneous
317 population growth approach on national level. They found an increase in population exposure to 1 in 100-year
318 coastal floods between 2010 and 2050 of 25% on global scale. In the basic approach, we find an increase of
319 population's exposure to 1 in 100-year coastal floods between 19% in SSP4 and 28% in SSP3. The exposure based
320 on the coastal approach grows from 2010 to 2050 between 33% in SSP3 and 50% in SSP5 and exceeds the
321 projections of Jongman et al. (2012). In agreement with Jongman et al. (2012), both approaches analysed in context
322 of this paper project the highest absolute growth in exposed population until 2050 for Asia and the highest relative
323 growth for Africa. However, the comparison of results to other studies proves difficult, as the underlying population
324 projections are different. For example, Jongman et al. (2012) used the medium Fertility projection of the 2006
325 Revision by the UN Population Division while this study is based on the work of KC and Lutz (2017).

326 The differences in population exposure between the approaches for the years 2005 and 2010 are due to using
327 differing definitions of 'urban' in the underlying data. The urbanisation projections rely on Jiang and O'Neill
328 (2017), which used the world urbanisation prospects (UN 2015) as input data that retains the urban definitions
329 used by each country. Across countries, the definitions are inconsistent. The coastal SSPs of Merkens et al. (2016)
330 used the GRUMP urban extents grid, which tends to underestimate urban extents in developing regions (see section
331 2.1). Hence, urban population is concentrated in the remaining settlements with night-lights, leading to higher
332 estimated population counts in these areas. As coastal areas in eastern and northern Africa are heavily populated
333 (Hinkel et al. 2012) and western Africa hosts important port cities with growing population (Hanson et al. 2011),
334 the inconsistencies in data trigger an offset in the initial exposure. In SSP4, which shows the highest relative
335 differences between the coastal and basic approach for Africa, the African population grows more than threefold
336 (KC and Lutz 2017) and the urbanisation level almost doubles until 2100 (Jiang and O'Neill 2017). This leads
337 presumably to an overestimation of exposure in the coastal approach. With SLR, the effects of the initial
338 inconsistencies in the data decrease, leading to a reduction of the relative differences of exposed population.

339 This study has focused on the differences in exposure that arise from using different approaches to regionalise
340 population projections. We interpret the differences in exposure between the approaches as uncertainty that is
341 related to regionalisation, as the underlying population projections on national level do not differ between the
342 approaches. Other uncertainties arise from elevation data and the base year population datasets used to assess the
343 exposure to 1 in 100-year. Elevation and population datasets can potentially be improved if data availability
344 improves and the need for modelling decreases. The uncertainties that arise from the downscaling approach can
345 be reduced to some extent, if the differences between reported urbanisation level and the urbanisation levels based

346 on remote sensing products find a better agreement. Other parts of the uncertainty cannot be removed, as the
347 projections are made for long timeframes and human behaviour cannot be predicted.

348 5 Conclusion

349 This study compared different approaches to account for population change in coastal impact assessment in order
350 to assess the exposure of population to 1 in 100-year coastal floods under different SLR and socioeconomic
351 scenarios. All approaches were based on the same population projections on national level. We found that
352 urbanisation and coastal migration lead to increased exposure whereas urban sprawl leads to reduced exposure.
353 This emphasises the need for taking into account population dynamics on subnational level in exposure
354 assessments. We believe that the exposure estimates obtained from approaches accounting for regional variations
355 in population distribution, such as urbanisation, coastal migration and urban sprawl, are more reliable than the
356 approaches not accounting for such variations. As coastal areas host a disproportionately large number of cities,
357 sub-national population dynamics are of particular relevance for coastal exposure studies and should not be
358 ignored. With rapidly growing cities in developing countries, the need to provide improved assessments of
359 population exposure to coastal flooding is important for global and national planning, both in terms of allocating
360 human and financial resources on national level and climate change adaptation funding on international level.

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