Status of global coastal adaptation

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The state of progress toward climate adaptation is currently unclear. Here, we apply a structured expert judgement to assess multiple dimensions shaping adaptation (equally weighted: risk knowledge, planning, action, capacities, evidence on risk reduction, long-term pathway strategies). We apply this approach to 61 local coastal case studies clustered into four urban and rural archetypes, to develop a locally-informed perspective on the state of global coastal adaptation. We show with medium confidence that today's global coastal adaptation is half-way to the full adaptation potential. Urban archetypes generally score higher than rural ones (with a wide spread of local situations), adaptation efforts are unbalanced across the assessment dimensions, and strategizing for long-term pathways remains limited. The results provide a multi-dimensional and locally-grounded assessment of global coastal adaptation, and lay new foundations for international climate negotiations by showing that there is room to refine global adaptation targets and identifying priorities transcending development levels.

Assessing headway on climate adaptation is a burning scientific and policy question[1-4] because, as today's global climate risk will experience a two- to four-fold increase by the end of this century depending on the global greenhouse gas emissions trajectory[5], we need to know the current status towards addressing its consequences. This question connects to other prominent topics on the observed and anticipated effectiveness of what is implemented at various scales[6-9], on adaptation limits and residual risks[10-11], on the potential shrinking of the range of options available[12], and eventually on whether humankind is on a path to adaptation or maladaptation (i.e. insidious risk increase over time, space and/or population groups)[13-15].

Recent analyses conclude that despite adaptation-related responses undertaken in all regions and sectors[11,16], global action remains incremental in scale. Policies and projects are usually short-sighted and focused on single hazards, generally narrow in scope as they inadequately address the root causes of climate exposure and vulnerability, and poorly monitored[3,16-18]. The Working Group II's contribution to the Sixth Assessment Report of the IPCC (IPCC AR6) also emphasizes that there is little evidence of effective risk reduction in relation to implemented responses —in ~3% of the >1,600 publications analyzed in ref.16— and hence it is unable to conclude whether we are on track to adaptation or on a pathway towards higher risks[9,11]. While these statements are important to raise awareness on the need to adapt, they also call for a more integrative understanding of the dimensions shaping adaptation on the ground: risk knowledge, effective planning and action, available capacities, long-term vision, etc.

Assessing adaptation in a more integrative way raises methodological challenges. They relate to the lack of quantifiable adaptation goals that can be used as baselines or targets, as well as to the difficulty of identifying sets of indicators and metrics that capture the complex nature of adaptation (e.g. beyond only quantitative GDP-related metrics), are relevant across contexts, and can be informed with reliable data[1,3,19,20]. Alternative approaches have been developed to overcome these issues[e.g.,21-26], but they remain in the minority.

This paper develops a qualitative structured expert judgment —the Global Adaptation Progress Tracker, GAP-Track— that involves 17 international experts with various backgrounds and 10-30 years of experience in coastal adaptation (Table SI7). It relies on a 0-4 scoring system associated with confidence levels and is framed by six overarching questions reflecting core physical and human dimensions of adaptation (Methods, see Panel A of Fig., SI1, SI7.1): knowledge about current and future climate risks (Q1), planning (Q2), action (Q3), capacities (Q4), evidence towards reducing climate risks (Q5), and long-term pathway strategies (Q6). Assuming all of these dimensions are of equal importance to describe deep adaptation in a comprehensive way, they are equally weighted (see 3-fold rationale in Methods). The study uses a bottom-up approach that aggregates local case studies to inform the global scale (Panel B of Fig. SI1) and is applied to coasts, since low-lying coastal settlements (<10 m above mean sea level) represent ~11% of the global population at densities and growth rates greater than the global average, and ~14% of the global GDP[27-29], and are concerned with severe climate risks such as coastal flooding[30,31]. In the end, GAP-Track allows capturing the "adaptation imprint" of a given system at a given time (i.e. adaptation efforts across different assessment dimensions, and here for coastal areas today; see glossary SI7.1.1.3), as well as the nature and extent of outstanding gaps. This framing helps moving beyond the quantitative indicator bottleneck and bringing multiple adaptation dimensions and sources of information together, and facilitates the rapid delivery of results[32-34]. Despite limitations (Box 1), this can be instrumental, from understanding local situations to informing the five-year cycle of the UNFCCC Global Stocktake (GST)[4,35] (see Box 2 at the end).

[INSERT BOX. 1]

The coastal archetype perspective

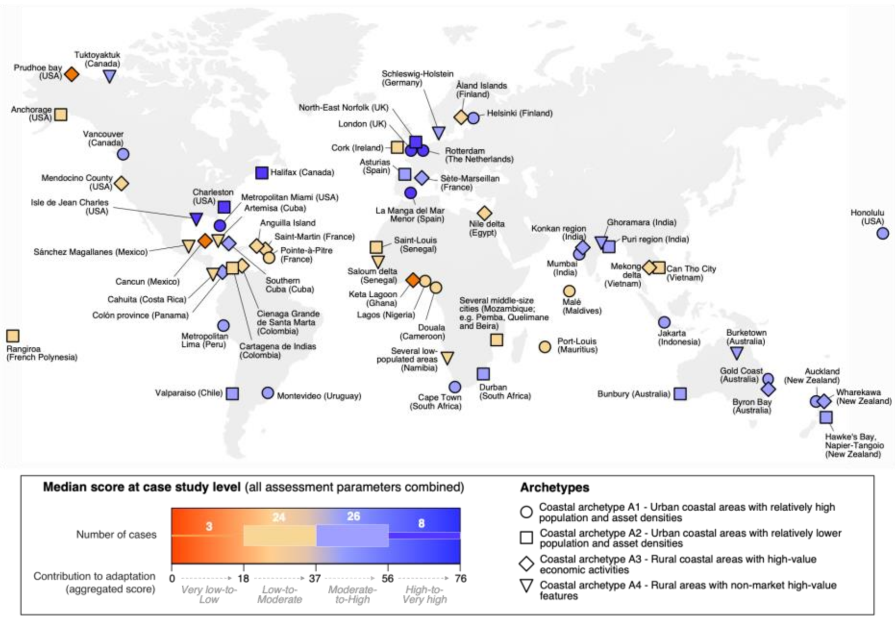
Local case studies are used to illustrate a diversity of situations within four generic coastal settlement archetypes (Table SI1 in Methods): (A1) urban areas with relatively high population and asset densities, i.e. big cities, relative to the country context; (A2) urban areas with relatively lower population and asset densities, i.e. middle-size cities; (A3) rural areas with high-value economic activities, e.g. agriculture or tourism; and (A4) rural areas with non-market high-value features, e.g. cultural or natural.

Insights from the local scale — The sample comprises 61 local case studies (Fig. 1, SI1.3.2, SI8), including 34 urban (19 and 15 for A1 and A2, respectively) and 28 rural (17 and 10 for A3 and A4, respectively). They are distributed across the seven world regions identified in the IPCC AR6: Africa (10 cases), Asia (7), Australia & New Zealand (7), Central & South America (9), Europe (10), North America (11) and Small Islands (7).

The case study-level aggregated scores across the assessment questions (min-max range 0-76; Methods, Fig. SI4e, SI6a-d) range from less than 20 for Prudhoe Bay, Keta lagoon, Cancun, Aland Islands, Nile delta and Namibian cases, to more than 60 for North-East Norfolk, Charleston, Isle de Jean Charles, Rotterdam and London. The median aggregated score is 39 (*Medium confidence*), with most cases below this level located in Africa, Small Islands and North America; and most cases above located in Australia & New Zealand, Europe, North America and Central & South America. Less than 5% of the case study-level aggregated scores are associated with *Low confidence* (3 cases, all in Africa), when ~44% and ~51% are associated with *Medium* and *High confidence*, respectively (SI4e).

About 44% of the cases show at best a Low-to-Moderate level of adaptation efforts (Fig. 1), especially in Africa and Small Islands (more than seven cases out of ten in both regions) due to lower adaptive capacities for example in Africa (Q4) and lower levels of long-term thinking in both regions (Q5 and Q6). Low-to-Moderate levels are also met, though to a lesser extent, in North America and Central & South America (both four cases out of ten). In contrast, ~13% of the case studies demonstrate High-to-Very high adaptation efforts, exclusively in Europe and North America (both about four cases out of ten), with an additional dozen of cases close to the Moderate aggregated score of 37-38, especially in Australia & New Zealand (seven cases out of ten) and Central & South America (a third of the cases). Overall, ~82% of the case studies range from Low-to-Moderate to Moderate-to-High levels (*Medium confidence*).

Fig. 1 | The local coastal case studies per aggregated score and archetype. The local case studies are clustered into four archetypes (symbols) and their aggregated scores (colors) are located along the whole scoring scale from 0 to 76 to indicate very low to very high efforts. Source data are available in Supplementary Data 1, sheets 5a–d and 6a.



An urban-rural gradient — Given that not all archetypes have the same number of case studies, case study-level aggregated scores across all assessment questions have been rescaled to allow comparing archetypes on a hypothetical 10-case basis (Methods, SI3b, SI4b), and come up with standardized median adaptation efforts. The results highlight a gradation from urban systems showing a Moderate-to-High median level, to rural systems showing a Low-to-Moderate level (*Medium confidence*), with urban and rural systems ranking respectively above and below the whole sample median score (ms 2.0; *Medium-to-High confidence*).

Densely populated urban systems score higher than less densely populated ones, with medians of 2.3 and 2.2 for A1 and A2, respectively (case study-level median aggregated scores of 44 and 43; SI6b). Rural systems hosting high-value economic activities score lower than the ones with non-market high-value, with medians of 1.7 and 1.9 for A3 and A4, respectively (case study-level median aggregated scores of 35 and 28; SI6c).

These results disguise the wide diversity of local situations within the archetypes, and with similar archetype-level standard deviations (~13; SI6c, Fig. SI4). Aggregated scores range from Low-to-Moderate to High-to-Very high in A1 (from 21 for Douala to 68 for London), A2 (from 22 for Rangiroa Atoll to 63 for Charleston), and A4 (from 20 for Namibian cases to 66 for Isle de Jean Charles). They range from Very low-to-Low to Moderate-to-High in A3 (from 10 for Prudhoe Bay to 49 for Wharekawa).

The spread is greater in some regions compared to others (SI6b). For example, Central & South America and Africa are characterized by more homogeneity in terms of the case study adaptation efforts than Europe and North America, with standard deviations of ~8, ~9, ~17 and ~19, respectively. This calls for some nuance when interpreting the above urban-rural gradient: while reflected in all regions, atypical cases are also to be considered in all regions. The Africa sample, for example, shows that A3 and A4 cases generally score lower than A1 and A2 cases, except for the rural Saloum delta (A4) that ranks higher than the urban cases of Douala, Lagos and Saint-Louis. The Europe and Small Islands samples similarly show one single atypical case (Cork and Rangiroa Atoll, both A2). Central & South America and North America show two atypical cases each: the Colon Province and Southern Cuba (A3) rank higher than Metropolitan Lima (A1) and Valparaiso and Cartagena (A2); and Anchorage (A2) scores lower than Tuktoyaktuk (A4), when Isle de Jean Charles (A4) shows the highest aggregate score of the North America sample, above Metropolitan Miami and Vancouver (A1). Asia is less consistent with three atypical cases out of seven (Can Tho City has the lowest aggregate score, while the rural Konkan region and Ghoramara rank higher than Jakarta and Mumbai).

The archetype-level adaptation imprints — The four archetypes have different adaptation imprints (Fig. 2). On risk knowledge locally (Q1), archetypes A1, A2 and A3 rank relatively High with respect to their cross-case study median scores, when A4 shows a more Moderate level (ms 3.0 and 2.0, respectively; *High confidence*; SI4b). A1 is characterized by higher knowledge on climate hazards (ms 4.0, Very high) than the other archetypes (ms 3.0, High). All the archetypes rank equally High (ms 3.0; *High confidence*) on knowledge on the drivers of exposure and vulnerability in natural and human systems. Climate risk projections depict a slightly different picture where urban archetypes score higher than rural ones (ms 3.0 and 2.0, respectively; *High to Medium confidence*). Intra-archetype spread however exists such as, for example, in Africa where Cape Town scores High when Lagos scores Low, or in Small Islands where Honolulu, Malé and Port-Louis score Moderate when Pointe-à-Pitre score Low.

On locally-relevant planning (Q2; SI4b), archetypes A1, A2 and A4 demonstrate an implementation gap. The A1 and A2 samples both show that adaptation efforts towards designing adaptation-related planning tools having concrete implications locally score High, but their implementation is Moderate (ms 3.0 and 2.0, respectively; *High confidence*). In A4, design is Moderate and implementation is Low (ms 2.0 and 1.0 and *High and Medium confidence*, respectively), and in A3 both design and implementation score Low (ms 1.0, *Medium confidence*).

Locally-led actions (Q3) score Moderate in all archetypes (ms 2.0, *Medium confidence*; SI4b). However, efforts towards implementing actions that target both prominent local climate hazards and main drivers of exposure and vulnerability in human systems, are higher in A1 than in the other archetypes (ms 3.0 and 2.0, and *High and Medium confidence*, respectively). This masks some spreading within A1 cases, as ~47% of them score Moderate or lower (e.g. Jakarta, Lagos, Mumbai, Pointe-à-Pitre) when ~53% score High or higher (e.g. La Manga del Mar Menor, London, Malé, Metropolitan Miami) (SI6c).

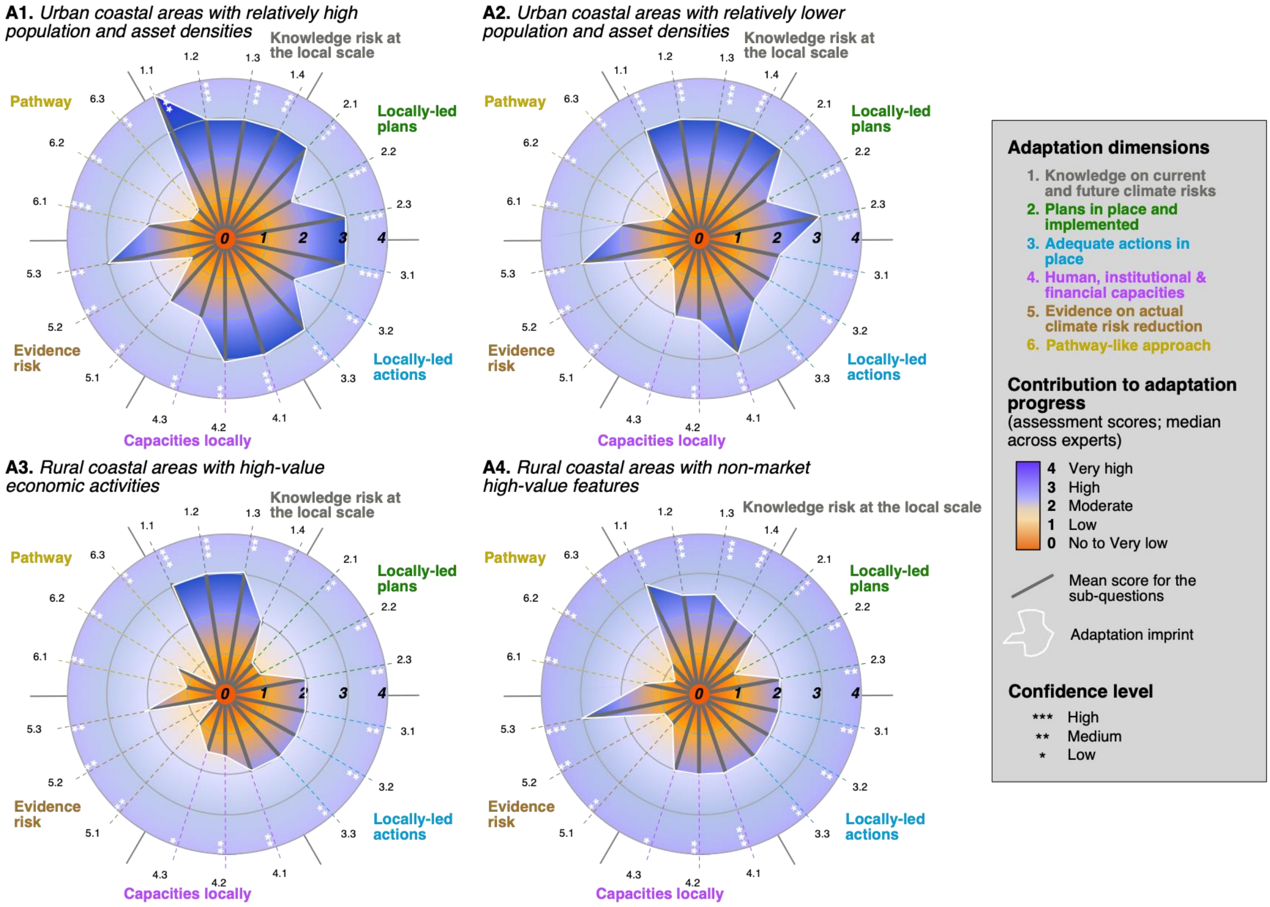
Regarding local capacities (Q4), the contribution of governance arrangements that are in place to support institutional capacities to coordinate adaptation activities locally, is High in urban systems and Moderate in rural ones (ms 3.0 and 2.0, and *High and Medium confidence*, respectively; SI4b). The picture is different when it comes to human capacities to support adaptation locally. Whereas A1 cases usually rank High, as illustrated by Metropolitan Miami or Cape Town, ~71% of the A2, A3 and A4 cases score Moderate (Anchorage, Anguilla, Artemisa, Burketown, Cork, Mozambique cases, Puri region) or Low (Asturias, Cahuita, Mendocino county, Saint-Martin island, Saloum delta; no cases in our Asia and Australia & New Zealand samples) (SI6c). The third assessment sub-dimension on capacities refers to the availability of sustainable funding locally that is specifically dedicated to managing climate-related coastal risk and adaptation —the analysis deliberately excludes whether this funding is enough or not compared to local needs. The contribution of available funding to adaptation efforts locally scores Moderate in A1, A2 and A4, and Low in A3 (*Medium to Low confidence*). More than 38% of the A3 cases even score No-to-Very low (ms 0; *Low confidence*): Aland Islands, Anguilla Island, Cienaga Grande de Santa Marta, Keta lagoon and Prudhoe Bay. In contrast, cases scoring High or higher (ms 3.0 or 4.0) on locally available funding do not belong to one type of situation (e.g. A1 in high-income regions) but are relatively equally distributed across the archetypes in high-income regions (Bunbury, Burketown, Byron Bay, Charleston, Gold Coast, Isle de Jean Charles, London, Metropolitan Miami, North-East Norfolk, Rotterdam) and, to a lesser extent, in lower-income regions (Artemisa, Colon province, Puri region, Southern Cuba). The overall conclusion on funding is however associated with *Low confidence* as this level characterizes four cases out of ten (SI5a-d).

The four archetypes demonstrate a similar Moderate to lower level of evidence on effective climate risk reduction today (Q5; ms 2.0, rather *Medium confidence*; SI4b), but their imprints vary. A1 ranks higher in terms of locally observed risk reduction (ms 2.0 compared to 1.0 in the other archetypes; *Medium confidence*), while A3 ranks lower regarding societal awareness (ms 2.0 compared to 3.0 in the other archetypes; *Medium to High confidence*). In addition, the extent to which locally-implemented policies and actions contribute to minimize the risk of maladaptation in the long run is estimated Low in A1, A2 and A4, and No-to-Very low in A4 (*Medium confidence*). There is of course some intra-archetype dispersion. On anticipating maladaptation for example, some rural cases score High (Cahuita, Isle de Jean Charles, Southern Cuba; *Medium to High confidence* depending on the cases), as do some urban cases (Charleston, Halifax, Rotterdam, Vancouver; *Medium to High confidence* depending on the cases). But overall, on anticipating maladaptation, High or higher median scores characterize only ~12% of the whole sample.

The archetypes all demonstrate limited imprints on the extent to which a pathway-like approach is considered (Q6; SI4b), with locally-relevant adaptation goals usually scoring slightly higher than the consideration of synergies-tradeoffs between multiple options and option sequencing over time (*Medium confidence*). Urban archetypes show a slightly higher contribution than rural ones on defining adaptation goals, but still at a rather Moderate median level, and though a third of the urban cases score Very high (all in high-income regions: Bunbury, Gold Coast, Hawke's Bay, Helsinki, La Manga del Mar Menor, London, North-East Norfolk, Metropolitan Miami, Rotterdam). In rural regions, one case out of four scores Very high (Artemisa, Asturias, Burketown, Byron Bay, Colon province, Isle de Jean Charles, Southern Cuba, Wharekawa), when most of the cases score Low or lower. On synergies-tradeoffs and option sequencing, all the archetypes score Low or lower (rather *Medium confidence*), with respectively ~54% and ~68% of the urban and rural cases reflecting this conclusion, against respectively ~26% and ~15% of the urban and rural cases showing High or higher levels (SI6c).

The adaptation gap at the archetype-level — The database allows characterizing the "adaptation gap", here defined as the distance between the assessed and theoretical aggregated scores, the latter being completed when all assessment questions score 4 (i.e. aggregated score of 76 at the case study level) and therefore describing a situation where the full adaptation potential is utilized (i.e. including locally-relevant soft adaptation limits are overcome; see Methods and glossary SI1.1.3). The analysis suggests that the gap is higher in rural systems than in urban ones, with respective median ranges of ~54-62% and ~42-43% (SI6d). A smaller urban gap however remains to be considered significant given the population sizes and economic assets involved. Atypical cases are reported in all archetypes, for example the A1 cases of Douala and Lagos showing higher gaps (~72% and ~68%, respectively) than the rural median, or the A4 case of Isle de Jean Charles showing a lower gap (~13%) than the urban median.

Fig. 2 | The coastal archetype adaptation imprint. The imprint reflects the level of adaptation efforts in each of the six dimensions considered in this study. It is designed based on the median score obtained across the whole case-study sample on the various assessment sub-questions. It also shows the confidence levels associated with all the median scores. The colour graduation in the background illustrates the scoring system used in this study. Source data are available in Supplementary Data 1, sheets 4a and 5a–d.



The global perspective

The material above allows combining all case studies and archetypes to describe the global status of coastal adaptation efforts and gaps.

A global snapshot — Considering all local case studies together allows scaling up the analysis and highlighting six global-scale conclusions on the state of coastal adaptation. First, the study confirms recent stocktake that adaptation is happening on the ground, but is not at scales[g.,3,16]. Assuming equal weighting across the 61 case studies and across the assessment questions (see Methods), the global median score reflects a Moderate level of coastal adaptation efforts (ms 2.0, *Medium confidence*; SI4d), indicating half-way progress to the full adaptation potential. Looking at the whole sample's median aggregated score (39, min-max 0-76; SI6a), ~44% of the cases demonstrate a less than Moderate level (range 10-37, mostly in Africa and Small Islands), when only ~13% show at least a High level (range 57-68, all in Europe and North America). North America illustrates the wide spread of local situations within a given region, with cases ranging from the lowest to the highest scores. Such a spread critically needs to be considered in order to nuance global-scale analyses such as under the UNFCCC that focus on Parties but disguise sub-national variation.

Second, the global coastal adaptation imprint is unbalanced (Fig. 3), demonstrating relative strengths and weaknesses. While risk knowledge scores relatively High (ms 3.0, *High confidence*), locally-led planning, action, capacities and evidence of risk reduction rank Moderate (ms 2.0, *High to Medium confidence*), and the pathway-like approach scores Low (ms 2.0, *Medium confidence*). Both evidence of risk reduction and the pathway-like approach demonstrate more variability among their sub-dimensions (ms ranges 1.0-3.0 and 1.0-2.0, respectively; *Medium confidence*), with key weaknesses on appraising present climate risk reduction (Q5.1), minimizing the risk of maladaptation (Q5.2), and developing a multi-option perspective (synergies-tradeoffs and sequencing, Q6.2 and Q6.3).

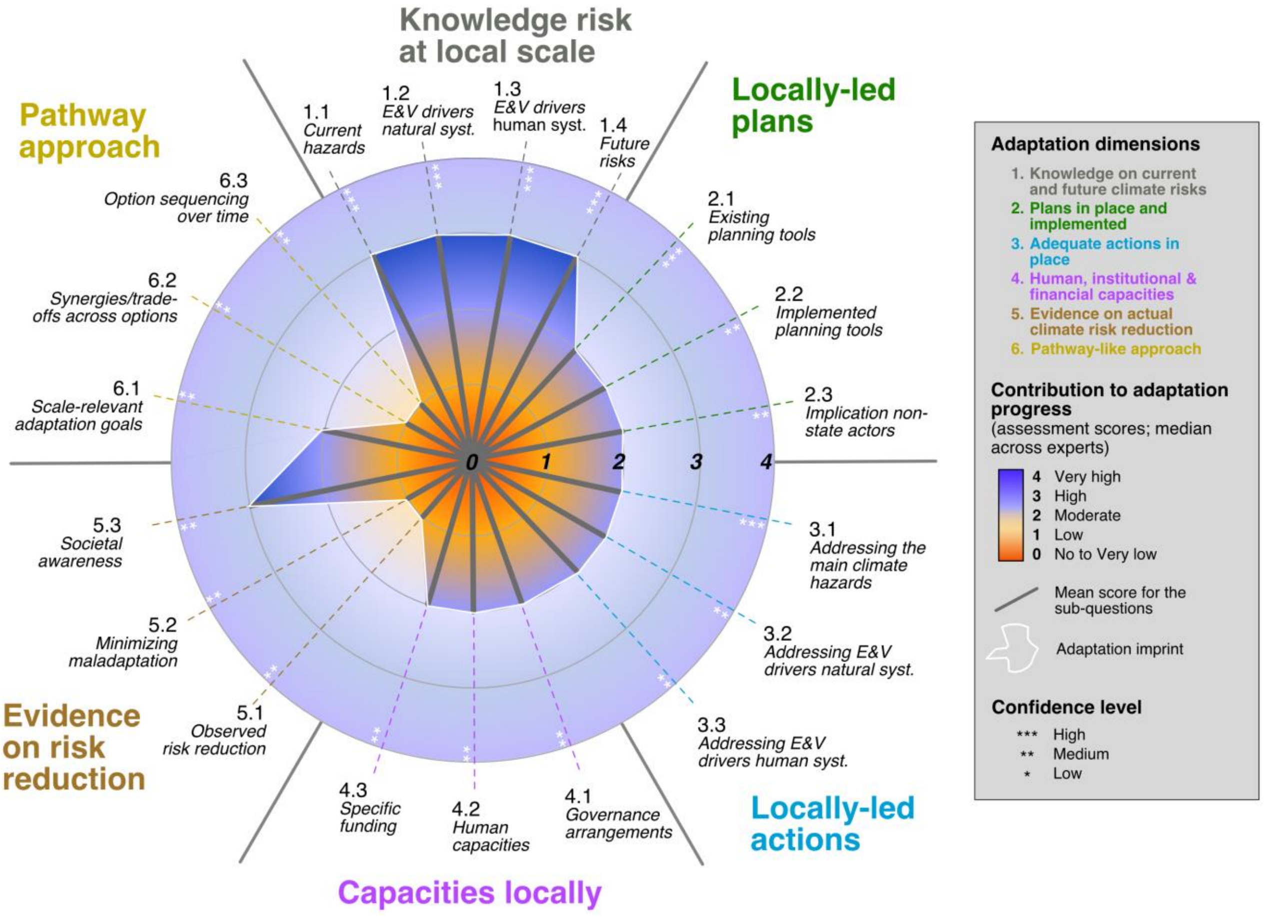
Third, the results concur with recent studies to conclude that adaptation efforts remain too narrow in scope[1,2,3,16,36]. For instance, locally-led actions remain at a Moderate level (ms 2.0, *High to Medium confidence*) in terms of addressing the main climate hazards and drivers of exposure and vulnerability in natural and human systems (Q3.1-Q3.3 in Fig. 3), while by contrast, these elements are relatively well known in general (Q1.1-Q1.3).

Fourth, this study challenges the conclusions established on adaptation planning based on cross-sector, national-level analyses. For example, the Adaptation Gap Report[3] concludes that more than eight countries out of ten are now equipped with at least one national adaptation planning instrument (plan, law, etc.), and that efforts are increasing towards a better implementation of these instruments through the consideration of future climate changes, the definition of objectives and timeframes for action, and the strengthening of science, national capacities and partnerships. A local and coastal-centered perspective however provides a different picture: ~60% of the cases score at best Moderate in terms of having designed locally-relevant adaptation planning tools, and ~79% score at best Moderate regarding the implementation of these tools (Q2.1 and Q2.2; SI6C). Such a result questions the relative disconnection or inertia between national- and local-level planning, confirming the need to also get a sense of the local perspective in regional to international analyses and, ultimately, policy processes such as the GST[20].

Fifth, the study confirms that local-scale adaptation efforts look incremental rather than transformational globally[2,16]. This is illustrated by the fact that forward-looking dimensions score Low, such as the minimization of the risk of maladaptation, the consideration of the synergies-tradeoffs between adaptation options, and option sequencing (Q5.2, Q6.2 and Q6.3; ms1.0; *Medium confidence*), hence suggesting that local adaptation remains rather short-sighted. Looking at the median scores combining these three assessment sub-dimensions, some cases in high-income regions show a more encouraging picture with High or higher levels (Charleston, Halifax, Hawke's Bay, Isle de Jean Charles, La Manga del Mar Menor, London, Rotterdam, Wharekawa; and only Southern Cuba for the lower-income regions). These cases however only represent ~15% of the whole sample, with ~34% and ~28% of the cases demonstrating respectively No-to-Very Low and Low levels (SI6c). This is all the more a concern that together with Moderate local capacities (Q6), evidence of observed climate risk reduction remains Low locally (Q5.1, Moderate or lower in ~83% of the cases; *Medium confidence*), preventing awareness raising on the need for a longer-term perspective in responding to coastal impacts[37,38]. Yet, to only take the example of sea-level rise, risks to low-lying coasts are already detectable with at least medium confidence in urban atoll islands, arctic communities away from rapid glacial isostatic adjustment, and large tropical agricultural deltas[39,40]. By the end of the century and in the absence of ambitious adaptation efforts, these risks will become significant, widespread and possibly irreversible in atolls and arctic coasts, the lower estimates for deltas being still of concern given these geographies' population sizes and economic importance globally[12,39-41]. This calls for implementing a longer-term perspective at the local level, which is not yet evident according to our results, though with some exceptions such as London that recognizes the possibility of high-end changes and takes a >100-year view.

Last, beyond the conclusion above that urban areas generally score higher than rural ones, the case study-level analysis concurs with other studies[e.g.,42] to suggest that no systematic correlation can be established between the level of adaptation efforts and either a given case study's population number or its region (SI6a-c). Five out of the nineteen A1 cases and nine out of the fifteen A2 cases show Moderate-to-Low adaptation efforts across all the assessment questions, when some small rural communities such as Isle de Jean Charles and Wharekawa are more advanced. Also, even the regions showing some homogeneity across their case studies (aggregated scores' standard deviations < 10) have cases spreading along the full range of median scores, for example from Very Low to High in Africa and from Low to High in Asia, Central & South America and Small Islands. North America and Europe show the highest spreading (standard deviations ≥17) with very contrasting situations from rather Low adaptation efforts in Aland Islands, Cancun, Cork and Prudhoe Bay, to far higher levels in Charleston, Isle de Jean Charles, London, North-East Norfolk and Rotterdam. Asia and Australia & New Zealand demonstrate the highest homogeneity, with respectively all and most of their cases ranking between Moderate and High.

Fig. 3 | The global coastal adaptation imprint. The background circular color graduation illustrates the scoring system used. The non-shaded area is called the 'adaptation imprint 'and reflects the level of adaptation efforts across the six overarching dimensions and 19 sub-dimensions assessed. It is designed based on the median scores obtained across the whole case study sample. Stars represent confidence levels. The remaining shaded area represents the adaptation gap. 'E&V 'means exposure and vulnerability; 'syst. 'means systems. Source data are available in Supplementary Data 1, sheets 4d and 5a–d.



The extent of the global adaptation gap — The analysis lands on a global adaptation gap representing ~49% of the full adaptation potential, with a range from ~30% for risk knowledge to ~62% for the pathway-like approach (SI6d). Almost half of the 61 case studies show an adaptation gap higher than 50%, and more than a fifth faces a High gap (>68%). This reinforces the above conclusion that coastal adaptation globally is not at scale today, mirroring other sectors[3,16].

The multi-dimensional and locally-grounded assessment developed in this study for coastal adaptation confirms the need to drastically scale up adaptation policy and action around the globe, from local governments and stakeholders to the international climate policy arena. This latter has a role to play in terms of galvanizing national to local action, especially through further clarifying global adaptation targets and shared priorities transcending development levels. What is argued here is that the approach developed in this paper can play a decisive role in helping refine both targets and priorities, as discussed in Box 2.

[INSERT BOX 2 HERE]

Acknowledgments

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Author contributions

A.K.M. conceptualized the study. All authors contributed to data collection, writing and editing. A.K.M. developed all the figures.

Competing interests

The authors declare no competing interests.

Additional information

The online version contains supplementary information (2 volumes) available at LINK TO BE ADDED

Data Availability Statement

All data and calculation are presented in the second volume of the Supplementary Material (Excel file).

Figure legends and captions (main text)

- **Figure 1.** The local coastal case studies per aggregated score and archetype. *Sources: Data-sheets SI5a-d and SI6a.*
- **Figure 2.** The coastal archetype adaptation imprint. The imprint reflects the level of adaptation efforts in each of the six dimensions considered in this study. It is designed based on the median score obtained across the whole case study sample on the various assessment sub-questions. It also shows the confidence levels associated with all the median scores. The color graduation in the background illustrates the scoring system used in this study. *Sources: Data-sheets SI4a and SI5a-d.*
- **Figure 3.** The global coastal adaptation imprint. *Sources: Data-sheets SI4d and SI5a-d.*

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Methods

This method overview is accompanied with Supplementary Information (SI): full database (Excel file, SI2 to SI6) and a PDF document detailing some scoping material (SI1), case study sample (SI7), assessment questions and scoring system (SI8), complementary results (SI9), and all case studies' score justifications (SI10).

Disclaimer: this work is based on a structured expert judgment (SEJ) method to assess adaptation efforts in coastal areas and across scales. It does not aim at quantifying the "amount" of adaptation *per se* —e.g. in economic terms—, but rather at positioning the cursor of adaptation efforts along a Very low to Very high continuum. The quantitative aspects in this study are therefore relative to this continuum, and should not be considered as gross values. Such an approach could raise criticism about the fact that qualitative assessments limit the possibility to develop quantified conclusions, or that it relies too much on the values, intuitions and tacit knowledge of those who develop the assessment. Yet, such criticisms can equally be applied to purely quantitative assessments, such as in the climate modeling science[34,48,50], where methodological choices are never exempt from qualitative assumptions involving the same values, intuitions and tacit knowledge. Pulkkinen and colleagues[50] write: 'the appeal of the value-free ideal largely rests on its association with objectivity and impartiality. However, the ideal has been challenged by philosophers of science who have demonstrated that social values are integral to research without threatening its objectivity or impartiality' (p. 4).

Overview of the approach – Fig. SI1 on p. 6 of the first volume of Supplementary Material (see Panel A in particular) illustrates the question matrix used for the SEJ (SI7.1.1, Table SI3). The assessment framework is applied to a series of local case studies in seven world regions, which are then aggregated to provide a global snapshot on adaptation efforts today (Fig. SI1, Panel B). It is applied to coastal adaptation as one key area of risk and adaptation priorities globally. Informing the global level based on a local-scale perspective is critical given that adaptation is often described as primarily a local-scale issue, but it raises methodological challenges that we address through a three-step approach. First, we describe global coasts based on four coastal archetypes that offer proxy illustrations of the diversity of situations around the world[39,40,51,52]. Second, in order to rely on grounded information and minimize the risk of losing granularity regarding the diversity of local context-specificities, the GAP-Track framework is applied to real-world local cases, several of them being used to inform a given archetype. Acknowledging that each case study would deserve a deep individual assessment, our study uses them to illustrate a diversity of situations within the archetypes, with a clustering process based on both similarities (e.g. for A3 in table SI1 below, non-urban areas + areas dominated by agriculture or tourism) and differences (a range of regions socioeconomic, demographic, and governance characteristics). Third, we use a 0-4 scoring system to assess adaptation efforts for each assessment (sub-)question and based on that, provide cross-question aggregated and median scores to semi-quantitatively describe adaptation efforts at the case study level, and then scale up the analysis through score aggregations at the archetype- and global-level. Compared to assessment using national average statistics or formal policy documents, such a three-step framework allows injecting the local perspective into global analyses of adaptation.

Adaptation scope – In the aim of developing a focused understanding of coastal climate adaptation efforts, this study limits the scope of adaptation to human interventions (policies, plans or actions) that intentionally address climate impacts (observed) and risks (not yet realized) by: reducing climate-related hazards (e.g. mangroves replanting that allows for ground elevation and therefore impacting relative sea-level); reducing exposure and vulnerability (e.g. hard and soft coastal protection, managed retreat, early warning systems); and/or enhancing adaptive capacity (e.g. ecosystem restoration, awareness campaigns, educational programs). The study does not consider adaptation interventions positive *a priori* (i.e. they reduce risk) and also takes into account the potential for maladaptation (i.e. risk increase over time and/or space). Accordingly, the following categories are considered: (i) adaptation-labeled coastal policies and actions (related to climate extremes or trends); (ii) risk reduction policies and actions targeting a short-term response, but considering longer-term implications; (iii) risk reduction policies and actions that do not consider a long-term perspective but, according to the study's experts, do not carry any risk of maladaptation; (iv) risk reduction policies and actions having potential short-term benefits over a specified area but, according to the study's experts, carry a risk of becoming maladaptive over space and/or time.
The study deliberately leaves aside non-climate adaptation-oriented interventions (i.e. processes and actions where the core goal is not to directly address climate risk), though acknowledging their potentially indirect beneficial and/or detrimental effect(s) on the root causes of climate exposure and vulnerability. It also excludes adaptation interventions occurring outside of the study system and having either a positive or negative influence on climate risks at the study system; except for national-level planning policies when they are considered providing enabling conditions or barriers to local-scale planning.

Coastal hazards considered – This study uses a multi-hazard perspective by considering both extreme events and slow onset climate change occurring at the study system, i.e. localities. Only the direct impacts of the following events are considered: coastal erosion, marine flooding, sea-level rise and extremes, soil and groundwater salinization, inland flooding resulting from heavy precipitations (e.g. resulting from a cyclone event, or river flooding), and permafrost thaw. Cascading and compounding effects are only considered implicitly.

Assessment framing – The SEJ is supported by a 0-4 scoring system associated with confidence levels (see below and SI7.1 and SI7.2), and framed by six overarching questions and nineteen sub-questions (Fig. 1 Panel A;): knowledge about current and future climate risks (Q1; hazards, as well as exposure and vulnerability drivers); planning (Q2; existing instruments, level of implementation, stakeholder engagement); action (Q3; adequacy to address the main climate risks); capacities (Q4; institutional, human, financial); evidence towards reducing climate risks (Q5; observed risk reduction, societal awareness, consideration of the risk of maladaptation); and the use of a pathway lens to describe long-term adaptation (Q6; goal-setting, consideration of synergies and tradeoffs between options, option sequencing over time).

Case study selection and archetypes – The real-world local case studies assessed in this study are located in all world regions, though some areas are not covered (e.g. Northeast Asia) (SI1.3, SI8). They describe a diversity of situations and are clustered into four generic coastal settlement archetypes that are fully described in Table SI1 in the first volume of Supplementary Material (p. 7) and mapped in Fig. SI3 in the same document (p. 32).
The local case studies have been selected based on the expert's view on the extent to which these cases are representative of the diversity of situations that can be found on the ground, in both urban and rural contexts, and in high-income and lower-income regions. Acknowledging that there is no ideal way to describe "representativeness", we looked for covering a diversity of local contexts through balancing between cases where we knew that some adaptation was happening (but without pre-empting any high or low level of adaptation efforts), and others that we selected without any preconceived idea on adaptation taking place or not.

Scoring system – The 0 to 4 scoring system describes gradual contribution levels of a given assessment question to adaptation efforts at the whole case study scale, i.e. when all assessment questions are considered (see Panel A of Fig. 1

and Table SI4 on p. 13 of the first volume of Supplementary Material; SI2, SI7.1.2, SI7.2). Each score is attributed a clear and precise definition (qualitative narrative) with specific criteria to be considered by the experts, as detailed in SI7.2 for all the nineteen assessment sub-questions. The 0 to 4 gradation in reflected in score description, e.g.: no information available (score 0); only partial knowledge on a very limited number of cases (1); in-depth knowledge for very specific cases (2); good to in-depth knowledge for a number of cases that are sufficiently representative of the diversity of the study context, thus allowing for scaling up the lessons learnt (3); and in-depth understanding for most to all of the situations within the study context (4). The "Not Assessed" (NA) option is used in case of a too important information gap.

Each score for each assessment question and each case study is accompanied with a textual justification and the sources of information used by the expert (mainly scientific literature and assessments, policy and planning documents, reports of NGOs, additional interviews; both in English and the local language of the case study), as detailed in SI10.

Score aggregation – The scoring system supports a semi-quantitative description of adaptation efforts at the case study level for each of the assessment questions. Based on this material, aggregations have been developed to reflect adaptation efforts across the assessment questions and at various levels (SI7.1.2.2): case study, archetype, and global. Three main types of **aggregation** have been developed:

- Aggregated scores at the case study level to allow for locating each case study along a min-max scale: from 0 when all assessment questions score 0, to 76 when all assessment questions score 4 (4 x 19 questions). Aggregated scores are then combined at the archetype and global levels, without applying any weighting system (see below). Qualitative adaptation levels are attributed to each intermediary ranges (equally distributed along the 0-76 scale; Table SI5): *Very low-to-Low* (score range: 0-18), *Low-to-Moderate* (19-37), *Moderate-to-High* (38-56), and *High-to-Very high* (57-76);
- Median scores describe the median contribution level of each assessment question at the case study scale. The use of the median instead of the mean reflects the 'majoritarian principle' that Majszak and Jebeile[34] consider as the equivalence of robustness in expert judgment compared to models: 'the more experts agree on a particular judgment, the more likely the judgment is supposed to be' (p. 36), provided the independence of each expert is ensured (as for models when inter comparison exercises). Median scores are used to compare the assessment questions both within and across the case studies, and ultimately within and across the archetypes (e.g. median of all scores for question Q1 and for all cases describing archetype A1). Median scores are scaled over the same original 0-4 gradient, so that final median scores of 4 and 1, for example, respectively indicate a *High* and *Low* contribution to adaptation efforts (Table SI4 above);
- Not all archetypes nor regions have the same number of local case studies (Excel SI3a), which led us to use rescaling coefficients in order to compare archetypes as well as regions on the same basis, here: a hypothetical 10-case basis (Excel SI3b for archetypes, Excel SI3c for regions).

Overall, no **weighting** has been considered neither across the assessment questions nor across the local case studies, archetypes or regions. The underlying rationale is three-fold:

(i) From a scientific perspective, none of the six adaptation dimensions in Panel A of Fig. SI1 (also Figs. 2 and 3) is to be considered more important than another to describe deep adaptation in a comprehensive way and at the global level. To our knowledge, no large-scale study covering a wide diversity of local cases in various regions has been developed that compare the respective role of the six dimensions considered in this study, so that establishing any hierarchy would reflect the authors' own value judgment —which is central when attributing scores, but detrimental if applied to the assessment framing itself— and would therefore not be scientifically robust;

(ii) In line with (i), we argue that any weighting of the relative importance of some assessment dimensions compared to others should reflect the study context's values and priorities, and is therefore not under the responsibility of scientists, but rather of national/local decision-makers, populations and economic actors, or of the UNFCCC international policy community in the case of global studies such as in this paper;

(iii) From a geographical perspective, adaptation in rural systems or small communities is in theory as important as in urban areas, so as adaptation in lower-income regions is as important as in high-income regions. One counterargument to this is that many people have a higher aggregated value than few people, which often lays foundations for decisions. While fully acknowledging this, here we advocate for considering all persons on this planet having the same "value" and being equally concerned with adaptation challenges. Such an ethical positioning in turn forms the foundation of the bottom-up approach to inform the global scale.

Confidence levels – To further ensure the robustness and transparency of the results, confidence levels are attributed by the experts on an individual basis and for each of their respective local case studies, to the case study scores for each assessment question (SI7.1.2.4). Confidence levels use the levels of evidence (from the sources of information) as a proxy. The framework (see Table SI6 on p. 15 of the first volume of Supplementary Material) consists of three main confidence levels associated with the main assessment scores, as well as two intermediary confidence levels used only during the aggregation process of confidence levels, i.e. when cross-question or cross-case study median scores have a decimal. On practice, to assess levels of confidence, each expert weighted the following two considerations equally: the robustness of the information (from publications, datasets, interviews, etc.) used to decide for a score; and whether that information or process (evidence) is estimated sufficient by the expert to match the score description of a given assessment question.

Adaptation gap – This study defines the "adaptation gap" as the distance between the assessed aggregated scores and the theoretical aggregated one when all assessment questions score 4, i.e. maximum aggregated score of 76 at the case study level. The theoretical aggregated score describes a situation where the "full adaptation potential" is utilized: all decisions and actions to avoid intolerable risks have been implemented at the local level, and have allowed to overcome soft adaptation limits (financial, institutional, technical and social)[10]; hard limits are however considered beyond the scope of this study (i.e. outside of the circles in Fig. 2 and 3). For the case studies for example, the adaptation gap is calculated by subtracting the aggregated score (i.e. across the assessment questions) to the maximum theoretical one (76). The result is then expressed in percentage (SI6d): from 100% when the case study-level assessed aggregated score is 0, meaning a 76 points gap, to 50% in the case of a 38 points gap (case study score of 38) and 0% when there is no gap (case study score of 76). Median adaptation gaps are then calculated at the archetype and regional levels, with the same framing describing the gap as a percentage value. The same approach applies to calculate the global adaptation gap across the six overarching assessment questions and the 61 case studies.

Who are the "experts"? – The 17 experts (SI7.3) involved in this study and co-authoring this paper have an extended background in climate change risks and adaptation science and practice, and each meets most of the following criteria: (i) a social science perspective; (ii) a robust knowledge on adaptation science and practice; (iii) experience with several areas and countries within a given region; (iv) experience with both urban and rural systems; and (v) a very open mind for expert judgment exercises. Each world region is covered by at least two experts. Table SI7 reports on each expert's background and years of experience in the coastal adaptation field.

Assessment steps – Six main steps included feedback loops and validation processes between individual expert assessments (median scores and confidence levels) and sources of information (evidence) (SI8.3, Fig. SI2):

- Step 1: the expert group coordinator selected the relevant experts based on a literature review and consultations; and organized discussions with the experts to present the approach and ensure a common understanding of the overarching framing, assessment questions and score descriptions.
- Step 2: first round of individual assessments and group-level synthesis. Each expert identified a set of real-world local cases to inform the 4 archetypes for a given region, with no strict requirement to coordinate cases among expert(s) focussing on the same region, and ran the assessment (scores + justifications + sources of information + confidence levels). Interactions between the experts (not only within the same region) allowed exchanging views on the score description to ensure there is consistency in the way each expert understands the score descriptions for different sub-questions, but with no intention to deciding collectively about the scores themselves. This minimized the risk of each expert being influenced by others. Based on this, the coordinator developed a first group-level synthesis to, first, oversee the case study-level evidence and identify potential gaps or areas where more information was needed; and second, calculate median scores and confidence levels (across experts and regions).
- Step 3: second round of individual assessments, in light of the guidance raised in the first round synthesis and based on interactions at the regional team level. Then a second cross-case study synthesis has been developed to describe the near-to-final group-level assessment.
- Step 4: collective discussions to discuss the potential areas of contrast (for example where confidence levels are still low) with the intent not to systematically harmonize scores, but rather clarify areas of disagreement. These collective discussions also dealt with preliminary conclusions and the overall narrative of the study.
- Step 5: final synthesis (scores, justification, sources of information, confidence levels; SI5a-d, SI10) and further analyses (SI4a-e, SI6a-d).
- Step 6: collective production of the paper.

Additional references to the Methods section

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Boxes

Box 1. Methodological limitations and challenges ahead

Expert judgment approaches can complement assessments relying on quantitative indicators or national policy documents[17,18,44], and therefore contribute to addressing international policy calls for having complementary tools[1]. Further applications of the GAP-Track however require addressing four main limitations.

Choosing the case studies — To what extent do the case studies represent the vast majority of local situations around the globe? Given that most of this study's experts identified cases based on their knowledge that some adaptation was happening locally (without pre-empting any high or low level of adaptation efforts), our conclusions may over-estimate today's coastal adaptation efforts, a classical bias with expert judgments[32]. This could be overcome through a more systematic and neutral approach to case study selection, together with including more case studies for a wider coverage across both archetypes and regions, as well as expanding the number and diversifying the profiles of the experts (e.g. both scientists and practitioners)[32]. On expanding locations, for example, the current paper misses cases in China and Japan, while coastal flooding in particular is a serious problem there. That means that next iterations should include more cases; how much would be enough remains to be debated.

Selecting the "most representative" information — The GAP-Track raises the inevitable question of subjectivity[32-34,45-48]: how to select and communicate the most representative information? In this study we address this concern by, first, relying on a very precise description of each score for each assessment question to enhance a shared understanding of adaptation efforts and metrics among the expert group, and support experts when selecting the most relevant information. Second, confidence levels associated with each score are used to minimize the influence of individual and collective value judgment or cultural bias (e.g. westernized vision of risk or capacities), and hence nuance the interpretation of the final results[33].

Weight the adaptation dimensions — While here we do not put any hierarchy among the six dimensions studied (risk knowledge, planning, action, capacities, risk reduction evidence, long-term strategies; see justification in Methods), in reality their relative importance to describe deep adaptation can vary from one study context to another, and according to varying values and priorities. Future applications of the GAP-Track could therefore rely on the development of context-specific weighting systems based on the affected stakeholders' views. At the global level for example, while it makes sense from a purely scientific perspective to not weight the assessment criteria, the international policy community could call for weighting some dimensions more than others, especially planning, action implementation and capacity (especially human and financial) as these dimensions are central to UNFCCC negotiations on adaptation. Introducing context-specific weighting systems could also help better consider the interdependencies that are occurring on the ground between the assessment dimensions, what this study considers only implicitly.

Assessing progress —The GAP-Track neither considers a specific baseline (i.e. a given past level of adaptation efforts) nor future benchmarks (i.e. adaptation targets under various warming scenarios), but rather takes a snapshot of where we stand today —which actually provides a baseline. This leaves a question open: where do we locate along the adaptation path? Implementing the GAP-Track on a regular basis (e.g. every five years, ahead of each GST) could help address this question, but in turn raises questions about the fact that the experts will not be the same over time, and so assessment and interpretation biases could change. The methodological structure of the GAP-Track (score narratives) minimizes this issue, and there are also encouraging signs from the IPCC. Since 2001, expert judgments are developed to assess the five "Reasons for Concern" that illustrate aggregated, cross-system and global-scale climate risks[49], with results showing risk level transitions occurring at lower global warming levels from one report to another[11]. The IPCC example shows that expert judgments can help highlight trends.

Box 2. Implications for international climate negotiations

This paper touches on the live issue in UNFCCC negotiations of determining the “adequacy” and “effectiveness” of adaptation action. In the GST context, these elements refer respectively to whether various instruments match the adaptation needs identified by countries and to the outcomes of such instruments, and are mainly analysed based on national communications (Nationally-Determined Contributions, Adaptation Communications, and National Adaptation Plans) and project-based international funding (Green Climate Fund, Adaptation Fund, Global Environmental Facility, and Multilateral Development Banks). Reviewing these sources of information is however not sufficient to get the full picture of adaptation efforts, which also requires a grounded, local perspective across regions. Accordingly, our results have the potential to inform three important policy questions.

How to operationalize the global goal on adaptation? Concluding that today’s global coastal adaptation is half-way to the full adaptation potential, meaning a ~50% gap, lays foundations for establishing targets beyond just coastal adaptation (see below), for example: reduce the local adaptation gap globally to 25% by 2050. Whatever the precise target, and considering that its setting has a major political dimension, this illustrates how the global goal on adaptation (GGA) could be made more practical. The establishment of the GGA under the Paris Agreement in 2015 marked a change by encouraging countries to think beyond the historic funding lens that structured UNFCCC negotiations[43] but to date, the vagueness of the GGA failed to instigate a real shift in action within and across nations[35]. Yet, periodically adopting a straightforward qualitative approach such as the GAP-Track can offer a way to track progress (Box 1) both globally and at the assessment dimension level.

Which scale of analysis for conducting the global stocktake? As shown here, no systematic correlation can be established at the local scale between the level of adaptation efforts and either the number of people (e.g. urban vs. rural) or the world region. This challenges the UNFCCC intrinsic divide between Annex I and Non-annex I countries. While this latter helps structuring the finance negotiation stream, it makes far less sense from a GST perspective because assessing adaptation progress globally requires considering all countries together. Our study suggests that appraising socio-geographical systems (here, coasts) helps transcend national circumstances and levels of development and, thus, both complement traditional country-driven approaches and highlight shared challenges. A way forward therefore consists of applying the GAP-Track to a wider range of key risk areas relating to other socio-geographical systems representing important human settlements worldwide (e.g. cities, mountains, Arctic regions, rural areas), biodiversity (e.g. transboundary ecosystems), and sectors acknowledged as having a critical influence on well-being (e.g. health, infrastructure, water and food security, peace). It is encouraging that the GAP-Track framework is not coastal-specific (e.g. SI7.2) and that its “local-for-global” framing is transferable to other topics.

Which priorities to close the adaptation gap? The GAP-Track framing and resulting adaptation imprints (Figs. 2 and 3) demonstrate the feasibility of considering multiple dimensions together in a single assessment, from risk knowledge to planning, action, capacities, evidence on risk reduction, and long-term strategies. Such an integrative understanding is decisive to support the international policy community in identifying global priorities per key risk areas, i.e. across countries. On coasts, for example, this study suggests five global priorities on (1) bridging the implementation gap in local planning; (2) further advancing the climate risk-related adequacy of local action; (3) scaling up local capacities (e.g. through ensuring governance arrangements make space for adaptation-dedicated funding); (4) developing scientifically-based guidelines for decision-makers, practitioners and funders to assess the effectiveness of their actions to manage and reduce risk; and (5) supporting a longer-term perspective in locally-relevant decision-making (options sequencing, pathways). The identification of such global-scale, cross-country priorities is critical to operationalize the GGA and the GST cycle, provided adaptation assessments consider multiple socio-geographical systems and sectors.