Estimating investments in knowledge and planning activities for adaptation in developing countries: an empirical approach

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Abstract
Costs of adaptation in the developing world have been mostly equated to those of climate proofing infrastructure under the assumption of unconstrained knowledge and planning capacities. To correct this, we introduce a cost-scaling methodology estimating sectoral investments to enhance the knowledge and planning capacities of countries based on an empirical collection of 385 climate-related projects. We estimate that circa 9.2 billion USD are required for financing knowledge and planning activities in developing countries in 2015. The agricultural and water sectors demand the higher investments – 3.8 and 3.5 billion USD, respectively. Average investments between 2015 and 2050 are projected at 7 billion USD per year – the largest fraction of which (4 billion) in Africa. Investments in this study were found to constitute approximately 40%, 20–60% and 5–15% of previous cost estimates to climate-proof infrastructure in the agricultural, water, and coastal sectors, respectively. The effort to finance the knowledge and planning capacities in developing countries is therefore not marginal relative to the costs of adapting infrastructure. The findings underline the potential of using empirical collections of climate-related projects for adaptation cost assessments as complementary to process and economic models.

Introduction
Economic assessments of adaptation in developing countries have been mostly concerned with determining the costs of implementing and climate-proofing infrastructure under the assumption of unconstrained knowledge and planning capacities. To correct this, we introduce a cost-scaling methodology estimating sectoral investments to enhance the knowledge and planning capacities of countries based on an empirical collection of 385 climate-related projects. We estimate that circa 9.2 billion USD are required for financing knowledge and planning activities in developing countries in 2015. The agricultural and water sectors demand the higher investments – 3.8 and 3.5 billion USD, respectively. Average investments between 2015 and 2050 are projected at 7 billion USD per year – the largest fraction of which (4 billion) in Africa. Investments in this study were found to constitute approximately 40%, 20–60% and 5–15% of previous cost estimates to climate-proof infrastructure in the agricultural, water, and coastal sectors, respectively. The effort to finance the knowledge and planning capacities in developing countries is therefore not marginal relative to the costs of adapting infrastructure. The findings underline the potential of using empirical collections of climate-related projects for adaptation cost assessments as complementary to process and economic models.

While there are conceptual insights on how knowledge and planning capacities shape the process of adaptation (Fankhauser & Burton, 2011; Moser & Ekstrom, 2010), a systematic investigation of investments associated with financing these capacities is currently absent. Three main reasons can be pointed on why the costs for knowledge and planning activities in the context of climate adaptation have received little attention.

The first is the canonical assumption in economic modelling about the existence of unconstrained capacities (knowledge, economic or institutional) of adaptation-promoting actors and countries to implement adaptation (Füssel, 2010; Patt, van Vuuren, et al., 2010). Few authors evaluate the economic consequences of implementing adaptation in developing countries in the lack of unconstrained capacities (de Bruin & Dellink, 2011). Accordingly, if the capacity to adapt is unlimited, determining costs in activities that enhance the knowledge and planning capacities for adaptation become unnecessary. While it could be argued that unconstrained capacities for adaptation exist in developed countries, the persistent adaptation deficit in developing countries (Fankhauser & McDermott, 2014) challenges the transferability of the assumption to all geographies.

Secondly, in order to estimate costs a particular level of adaptation needs to be determined or assumed. In the context of costing infrastructure the level is usually that required to offset the projected impacts from climate change. For example, the height and length of a sea-dike (adaptation option) is that required to offset the estimated height and losses from sea-level rise and associated flooding (Hinkel, Nicholls, Vafeidis, Tol, & Avagianou, 2010; Kirshen, Knee, & Ruth, 2008). The same approach is not easily transferable when it comes to setting the adequate level of options to enhance the knowledge and planning capacities of a region, given the lack of a direct link between climate impacts avoided and a country’s capacity to adapt. In order to overcome this, studies have relied on rule-of-the-thumb assumptions to set the level of investments knowledge and planning activities in climate-sensitive sectors.

Keywords
Adaptation process; project database; administrative units; costs of infrastructure
This has been done more noticeably for the agricultural sector. Investments in knowledge to respond to climate change were determined by assuming a 10% increase in research and development (R&D) expenditure between 2010 and 2030 (UNFCCC, 2007). A similar, slightly more dynamic, approach was followed in World Bank (2010).

Third; identifying a broad range of activities relevant for enhancing the knowledge and planning capacities of countries is not a straightforward exercise. Consequently, economic assessments have taken very general approaches in this respect. Catalyst (2009) made use of official budgets from research, weather-forecasting and national environmental agencies in developed countries as investment-analogues for financing the planning capacities of developing countries. An alternative is to make use of extensive collections of adaptation projects approved for financing (e.g. under the United Nations Framework Convention on Climate Change (UNFCCC)) as empirical basis to assess the range of adaptation activities. This approach allowed Biagini, Bierbaum, Stults, Dobardzic, & McNeely (2014) to develop a total of 10 adaptation typologies to categorize the adaptation activities; among these Information, Capacity building and Management and planning. Authors also note that the logical next step would be an evaluation of the costs associated with the adaptation activities falling within each adaptation typology.

A number of studies investigating the costs of adaptation underline how the financial needs for knowledge and adaptation are not explicitly consider in the design and operation of the costs methodologies. Ward et al. (2010) conduct a global study of adaptation costs for the water sectors focusing only on the 'the direct construction, implementation, and Operational and Management (O&M) costs associated with the adaptation measures considered'. In the costal sector, Neumann, Hudgens, Herter, & Martinich (2011), evaluates adaptation costs as those of coastal armouring, maintenance cost and beach nourishment costs, with no explicit mention of other adaptation costs beyond those enumerated. Ranger et al. (2011) conducts a study on urban flooding and equates adaptation for Mumbai by assuming a reduction in 15% of region’s vulnerability due to the implementation of building improvements incentivized by building codes and improved drainage system. Although the authors acknowledge the importance of monitoring, early warning, emergency planning, risk modelling and risk education as important risk-reduction measures; the economic assessment does not explicitly make an account of the financial needs implied by these options. In a cross-country analysis for Albania, Moldova, Macedonia and Uzbekistan, Sutton, Srivastava, and Neumann (2013) undertaken a cost-benefit for agriculture adaptation. The assessment determines the benefit rations for both infrastructure (e.g. rehabilitating existing drainage infrastructure, and non-infrastructure options (e.g. changing crop varieties). The authors note that not all adaptation options were treated with the same level of detail given, in particular, due to the lack of benefit information/specific crop for the option of expanding R&D.

The objective of this work is to propose, and operate, a new cost methodology that tries to alleviate the highlighted challenges. In doing so, we provide to date the first systematic estimate of investments in knowledge and planning activities required for adaptation in developing countries.

As an empirical basis of the manuscript we make use of 385 climate-related projects in developing countries to characterize the process of adaptation; 64 of which are then used in the economic analysis. The database was gathered in cooperation with the German Technical Cooperation (Deutsche Gesellschaft für Internationale Zusammenarbeit) (GIZ). The number of projects documented provides a more faithful (though not perfect) representation of adaptation activities than that considered in similar studies (e.g. see UNFCCC, 2007).

We link individual projects contained in the adaptation database to the three phases of adaptation described in Moser and Ekstrom (2010). By doing so we differentiate between projects that support the understanding and planning of climate adaptation and those that are better understood as specific implementations of the latter. Knowledge and planning activities selected are then evaluated in terms of their yearly costs, time duration and spatial scale of implementation. Lastly, the level of knowledge and planning suggested for adaptation was equated to the number of years a developing country (in 2015) is expected to remain below the 0.8 threshold of Human Development Index (HDI). The rationale behind this choice was linked to the existence of an inverted-U relationship between HDI and climate-related disaster losses (Patt, Tadross, et al., 2010). The shape of the relationship points for the existence of a level of development beyond which hazard losses in a given country decrease with increasing values of HDI. We interpret this point of development as that in which the overall capacities of a country to cope with climate-related hazards is in place. Investments needs are determined for 86 developing countries in 2015 and projected until the year 2050.

This paper is structured as follows: In ‘Data and methods’ section the database of climate-related projects is introduced and the overall methodology for determining investments in knowledge and planning activities described. ‘Results’ section contains the economic estimates obtained by sector and world region for the 2015–2050 timeframe. In ‘Discussion’ section, we contrast the estimates of investments developed in this study with (a) the cost figures of adaptation for hard infrastructure, and (b) international funds available for adaptation. Lastly, we highlight the main contribution of this work to the adaptation cost literature and future prospects in ‘Conclusions’ section.

Data and methods
Project database
The database of climate-related projects underpinning the economic analysis in this study is available for consultation at the Ci:Grasp web-platform (see Supplementary material). In this database, a climate-related project is defined as ‘an applied or planned action that aims to reduce the consequences of climate hazards and climate variability and is defined for a specific geographical region’. The overall objective Ci:Grasp is to support developing countries in developing their adaptation strategies and has originated as a combined effort between the Potsdam Institute of Climate Impact Research (PIK) and the German Technical Cooperation (Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)).
At the time of writing, the database is composed by 385 projects spread across 32 countries and 4 economic sectors. The information on projects is available in a structured form according to a total of 12 variables. For the purposes of this work only the variables shown in Table 1 are used. The database relies on the participation of adaptation-promoting actors and institutions reporting the adaptation initiatives. Each project entry is only made publicly available after an internal quality control and only if more than 50% of the documented information is provided.

**Linking projects to the phases of the adaptation process**

Although multiple theoretic frameworks are available to describe adaptation in socio-economic systems (Preston, Westaway, & Yuen, 2011; Wise et al., 2014), an accepted high-level conceptualization is that of adaptation as a process composed by three broad phases; a phase of Understanding of the climate threat, a phase of Planning for adaptive options, and a phase of Managing the selected options (Moser & Ekstrom, 2010), see Figure 1(A). Being a process, the success of the Managing phase is conditional to the actions undertaken during the Understanding and Planning phases. Accordingly, the activities in these two phases are taken as a proxy for those required for enhancing the overall capacities of countries for adaptation. By using the concept of adaptation as a process we wish to highlight that adequate funding in projects associated with understanding and planning phases increases the chances of success of the managing phase. This work is focused on approximating investments required to finance a bundle of projects to enhance the general knowledge and planning capacities of an economic sector within a given region. We do not assume that a lack of funding in actions guided towards these phases will stop adaptation altogether but rather that it will pose risks to its efficiency.

Using the adaptation process as conceptual background, the projects are allocated to each phase as follows. In the Understanding phase, the initial problem framing takes place through information gathering and awareness raising. Adaptation projects coded as Assessment report or Communication (see variable project type in Table 1) are allocated to this phase. The Planning phase involves both the development and selection of adaptive options. It is assumed that projects coded as Coordination, Technical Advice and Training contribute for fulfilling the objectives of the planning phase and are therefore allocated to it. The remaining project types – Building, Incentive Structures, Natural Resource Management, Regulatory and Relocation – denote concrete actions to adapt to climate change and hence are associated with the Managing phase. Only projects with complete information for the variables in Table 1 are used. The allocation of projects relies on the expert judgement (see project database) of the person responsible for the project to allocate it into one of the pre-established. On this premise, and because the person could only allocate one project to one of the above-mentioned categories, we need to assume that the allocation has been done to the category that better summarizes the main objective of the project.

Projects allocated to two or more sectors are disregarded in order to avoid double counting of costs. In total, 64 projects are considered under the phases of Understanding and Planning and used in the forthcoming economic analysis (see Figure 1 step A). It is relevant to point out that the allocation of projects to adaptation phases could be made in multiple ways (as the phases are themselves interconnected), and that there is no guarantee that the pool of projects gathered entails all the required actions for enhancing the capacities of developing countries in the context of climate adaptation.

**Determining investments**

The projects identified in the previous section are grouped according to their spatial scale of implementation (Local, Regional and National, see Table 1). The distribution of yearly costs of projects in each spatial scale is determined and the Inter Quartile Range (IQR) calculated. The IQR is the interval of the distribution placed between the 1st and 3rd quartiles and considered the most significant basic robust measure of the statistical dispersion in a set of numerical data (Tukey, 1977). The yearly costs falling within the IQR are summed and used as the indication of the investments required for knowledge and planning activities at each spatial scale (see Figure 1 step B). The sums of investments by spatial scale are then broken down to economic sector according to the fractions of projects documented in the Agriculture, Water, Coastal and Forestry sectors. Arguably, the best option would be to avoid this step and analyse directly the sum of costs in the IQR of projects within a given sector and scale of implementation. Following this approach would dramatically reduce the number of projects available in each category. Thus it was decided to keep the samples of projects from which costs are extracted the largest possible.

In order to estimate investments to the developing world we devised the scaling procedure illustrated in step C of Figure 1. First, the investments by scale and sector obtained in step B are allocated to the administrative units (AUs) of each developing country. To achieve this we make use of the Global Administrative Areas database (GADM) which contains information on the number and location for three levels of AUs, namely: level-0 (which refers to countries), level-1 (representing states or provinces) and level-2 (mostly referring to counties or municipalities). The estimates of investments by sector and spatial scale determined in step B are allocated to each AU of each developing country as follows: National investments are allocated to the AU level-0; Regional investments to each AU level-1 and Local investments to each AU level-2. Because of the geographic location of each AU, adaptation in every single sector of those considered is no realistic. For example, it is not

| Variables | Units/classification | Completeness |
|-----------|---------------------|--------------|
| Sector    | Agriculture; Water; Forest; Local; Regional; National | 100% |
| Spatial scale | Years | 84% |
| Running time | US Dollars | 64% |
| Costs | Technical advice; Communication; Training; Building; Incentive structures; Natural resource management; Regulatory; Relocation | 100% |
logic to have investments for enhancing knowledge and planning capacities in the coastal sectors for AUs without coast, the same logic applies to the forestry sector in AUs where the dominant land-use is urban or grassland. Accordingly, investments in knowledge and planning activities for the coastal sector are only accounted in the AUs bordering the ocean and investments in the forestry sector are only accounted in the AUs possessing forest-land. The later were identified by over-laying the spatial extent of the AU with the land-cover data in Erb et al. (2007). Finally, it is assumed by the authors that adaptation in the agricultural and water sectors are required in all AUs given the relevance of these sectors is providing basic human livelihoods (Lissner, Reusser, Schewe, Lakes, & Kropp, 2014).

While the previously described approach scales investments in space (via the number and location of the AUs of each country), of particular interest to policy-makers is how the required investments evolve in time. The most critical aspect to attend in this regard is to anticipate the year by when a developing country possesses the adequate level of knowledge and planning capacities enabling it to run the managing phase of adaptation as efficient as possible. Strong investments in the understanding and planning phases would be required while such level is not reached. Given that no objective way of measuring the knowledge and planning capacities of a country exist – in fact this is one of the issues that hinders economic analysis to capture this facet of adaptation costs, see Introduction – in this paper we assume that an adequate level of knowledge and planning capacities is reached when the HDI level of a country is equal to 0.8. Beyond this HDI level, the basic knowledge and planning capacities for adaptation are assumed to be in place. The rationale behind this choice was linked to the existence of an inverted-U relationship between HDI and climate-related disaster losses (Patt, Tadross, et al., 2010). The shape of the relationship points for the existence of a level of development beyond which hazard losses in a given country decrease with increasing values of HDI. We interpret this point of development as that in which the overall capacities of a country to cope with climate-related hazards is in place. Following our approach, yearly investments are integrated in time while the respective country’s HDI is below 0.8 and cease to be accounted once the HDI of a country is projected above the given threshold. Country-based projections of HDI are taken from Costa, Rybski, and Kropp (2011). The economic analysis is restricted to developing countries as identified in Malik (2013).

**Results**

**An empirical picture of the adaptation process**

Figure 2 shows the allocation of climate projects to the different phases of the adaptation process (see Data and methods), and their distribution according to economic sector. Projects associated with the Understanding phase of adaptation were found to constitute 25% of the projects documented in each sector. A similar pattern is observed in the case of projects associated with the Planning phase (about 20%). Accordingly, the number of projects related to the Understanding and Planning phases of adaptation comprises about 50% of the projects documented. From the number of projects alone half of the documented actions are linked to the early stages of the adaptation process. An imbalance of projects towards the agricultural and water sectors was noted. These constitute respectively 40% and 30% of the projects documented. This evidence is on line with the sectors where climate change impacts are expected to hit the first (Nath & Behera, 2011).

Climate-related projects coded as Building, and hence indicative of infrastructural options, do not account for more than 15% of the total projects considered in each sector. The highest fraction of such projects is found on the coastal sector, while the lowest is observed in the forestry sector (about 5%). It cannot be excluded that infrastructural options may be included in the projects coded, for example, as ‘Natural resource management’. However, the point made from our empirical analysis is that adaptation entails a much larger constellation of actions than those usually considered in future estimates of adaptation costs (see Parry et al. (2009), Fankhauser (2010) and references within). Accordingly, economic assessments that disregard this variety might be at the same time disregarding a substantial fraction of adaptation costs.

**Costs of projects by scale and sector**

The distribution of yearly costs for projects allocated to the Understanding and Planning phases of adaptation is shown in Figure 3(A) and sectioned according to each spatial scale of implementation. Overall, it has been observed that the majority of the projects considered present yearly costs equal or below 1,000,000 USD (grey vertical line). Although more expensive project do exist (e.g. above 3,000,000 USD yr⁻¹), in particular, those with a regional scale of implementation,
such projects are rare in the database considered. Projects with a local scale of implementation are observed as a least costly in our sample. The long tails observed in the local and regional distributions highlight the existence of few, but costly, projects. By contrast, the distribution of project costs with a national scope is rather homogeneous. Although overall distributions of national and regional costs are quite distinct, the respective IQR (highlighted in orange) is similar. In quantitative terms, the upper limit of the IQR for the regional and national distributions is placed at circa 1,000,000 and 900,000 USD yr$^{-1}$.

![Figure 2. Fractions of projects by sector, project type, and adaptation phase. Fraction of projects per sector reads on the top x-axis, fraction of project types reads on the left y-axis. $N = 385$.](image)

![Figure 3. Distribution of yearly costs of projects linked to the understanding and planning phases of adaptation (A). Sum of projects costs within the IQR (B). Fraction of projects by sector for each spatial scale of implementation considered (C).](image)
respectively. In case of the cost distribution of local projects, the IQR drops considerably to circa 50,000 USD yr\(^{-1}\).

Following, the yearly costs of projects falling within the IQR of each implementation scale are summed and the results expressed in Figure 3(B). As a reflection of the highly skewed distribution in Figure 3(A), the costs associated to the regional scale range the highest estimated – approximately 6,000,000 USD yr\(^{-1}\) – followed by those obtained for the national and local scales, respectively 3,000,000 and 300,000 USD yr\(^{-1}\). These values compose the basis for the calculation of investments needs to finance knowledge and planning activities by sector and spatial scale (see Figure 1 step B). We achieve this by multiplying the cost in Figure 3(B) by the project fraction by economic sector expressed in Figure 3(C). In line with the overall distribution of project shown in Figure 2, the highest shares of projects associated with knowledge and planning activities are observed in the agricultural sector. At the local scale, these account for about 40% of the projects considered (see Figure 3(C)), followed, in decreasing order, by projects for the water, coast and forestry sectors. At the national level, projects linked to the water and agricultural sectors constitute (in almost equal terms) more than half of all projects considered. At the national level, the fractions of projects in each sector are more balanced than at the local level where agricultural projects take the largest share.

The results of the disaggregation of costs in Figure 3(B) by the fractions in Figure 3(C) are presented in Table 2. The results are used as indicative investments for financing the knowledge and planning activities for adaptation in the corresponding AU’s of developing countries (see Figure 1 step C).

### Estimated investments for developing countries

Figure 4(A,B) respectively shows the total 2015, and projected 2015–2050, investments associated with knowledge and planning activities for a total of 86 developing countries. The results are shown aggregated to the four sectors investigated and three World Bank geographic regions.

When all sectors are considered, investments for financing projects belonging to the understanding and planning phases of adaptation in 2015 amounted to about 9.2 billion USD. Approximately 40% of this value (3.8 billion USD) is required for the agricultural sector alone, followed by the water sector (3.5 billion USD), forestry (1.1 billion USD) and coasts (0.8 billion USD). When all sectors are considered the largest fractions of investments are returned, in equal parts, to the regions of Africa and Asia and Oceania. The same is true regarding the agriculture and water sectors, while for the coastal and forestry sectors the region of Asia and Oceania dominates the investments estimated. Given the small number of developing countries (HDI below 0.8), the region of the Americas account for the lowest estimated investments, about 1.2 billion USD yr\(^{-1}\) when all sectors are considered.

A tentative projection of costs between 2015 and 2050 (see Figure 4(B)) shows a strong reduction in yearly costs for the next 15 years, from 9.2 in 2015 to circa 6 billion USD yr\(^{-1}\) in 2030. This reduction is driven by the expected fast achievements in HDI projected for developing countries in the Asian and Oceania and Americas regions (Costa et al., 2011). Beyond 2030 the decline in investments for developing countries is

### Table 2. Estimated costs (USD yr\(^{-1}\)) for knowledge and planning activities for adaptation by sector and spatial scale (values rounded).

| Sector   | Local  | Regional | National |
|----------|--------|----------|----------|
| Agriculture | 140,000 | 2,100,000 | 790,000 |
| Coast     | 80,000  | 1,000,000 | 730,000  |
| Forestry  | 50,000  | 1,000,000 | 490,000  |
| Water     | 80,000  | 1,900,000 | 670,000  |

Figure 4. Current (2015) yearly investments associated with knowledge and planning of adaptation in developing countries (A) and those projected for 2015–2050 period (B).
much lower. The sluggish improvements in the HDI estimated for many African countries results in a persistent need of financing the understanding and planning phases of adaptation at a near-constant rate of 4 billion USD yr\(^{-1}\) between 2015 and 2050. Integrating the investments in time results in 240 billion USD for financing the understanding and planning phases of adaptation in the developing world, about 7 billion USD per year until 2050.

**Discussion**

In the perspective of expanding the relevance of our results for policy-making and cost literature, the economic estimates of this study are compared with (1) the financial resources committed to adaptation in international frameworks, and with (2) the adaptation costs published for infrastructure (see Table 3). The comparison highlights on the one hand how financial resources available for adaptation rank to those in this study. The comparison is made using estimates of available adaptation financing in Smith et al. (2011), Buchner et al. (2014) and Olhoff et al. (2014). On the other hand, we expect to infer if the costs associated with the understanding and planning phases of adaptation are low, moderate, or high when compared to the costs suggested for infrastructure, e.g. World Bank (2010), Ward et al. (2010) or Hinkel et al. (2012). In this case, the comparison is done by determining the percentage of the costs estimated for infrastructure that correspond to the investments suggested by our estimates, see Table 3.

In 2011 the total available adaptation financing for developing countries was estimated between 1 and 4 billion USD per year (Smith et al., 2011). The 9.2 billion figure estimated in this study (in 2015) implies that funds reported in Smith et al. (2011) were 5–8 billion USD short of those required to finance the understanding and planning phases of adaptation in developing countries. Since then adaptation financing has evolved fast and in 2014 about 25 billion USD have been made available for adaptation focused activities (Buchner et al., 2014), in 2016 the figure dropped to 22 billion USD (Buchner et al., 2017). While the bulk of funding is now about 3 times the investments suggested in this study, a sectoral breakdown of available funding exposes important differences between sectors. Total adaptation finance for agriculture plus forestry in 2014 was estimated at 2 billion USD (Buchner et al., 2014) and about 4.2 billion USD in 2016 (Buchner et al., 2017). Our estimates for these two sectors ranges at 5 billion USD yr\(^{-1}\); meaning that the total funding available falls short of that proposed to financing the understanding and planning phases of adaptation. Region-wise, a total of 3.9 billion USD for adaptation in 2014 has been allocated to the Sub-Saharan Africa. Interestingly, this is the same amount of investments estimated for financing the understanding and planning phases of adaptation in 2015 (see Figure 4(A)).

In Table 3 the estimates developed in this study are further compared to adaptation costs figures from assessments focusing on the implementation of infrastructure. In the agricultural sector, the costs for road construction and irrigation in developing countries (DC) have been estimated at 5.8 billion USD yr\(^{-1}\) (2010 to 2050) (World Bank, 2010). Investments for the agriculture sector in this study (averaged throughout the same timeframe) come to around 2.2 billion USD yr\(^{-1}\), or in other words, 38% of the costs suggested for infrastructural costs for increasing reservoir yield in developing countries were estimated at 10 billion USD yr\(^{-1}\) (2010–2050) (Ward et al., 2010), while the costs of climate-proofing water infrastructure in Africa (A) and Sub-Saharan Africa (SA) at 3.5 (by 2030) and 2.7 billion USD (currently), see Table 3. The cost estimates in this study for the water sector averaged 1.6 billion USD yr\(^{-1}\) between 2015 and 2050 for all developing countries, and 2 billion USD yr\(^{-1}\) (2015–2030) when only the African region is considered. As result, investments associated with the early stages of adaptation for the water sector could comprese between 20% and 60% of those for climate-proofing water infrastructure.

The lowest ratio between investments for investments for knowledge and planning activities and those of implementing infrastructure are observed in the coastal sector. The investments to finance the understanding and planning phases of adaptation in Africa were determined at about 0.3 billion USD yr\(^{-1}\) (averaged between 2015 and 2050). When compared with the costs of coastal protection (see Table 3), financing the knowledge and planning activities constitute about 5–15% of the infrastructural costs for adaptation at the coastal zone. It should be pointed that the estimates regarding the coastal infrastructure in Hinkel et al. (2012) run until 2100, while the estimates in this study stop by 2050. This highlights the fact that comparing costs across different authors is never straightforward due to heterogeneous temporal and spatial coverage of studies. Care was taken to make the comparison as meaningful as possible, e.g. costs estimates for R&D in World Bank (2010) are removed as they are thematically close to those focus of this study while in the coastal sector only costs of dikes are used in order to reflect the costs of hard infrastructure. The numbers from Hinkel et al. (2012) refer to the costs of adaptation that are additional to those for covering the adaptation deficit.

**Critical methodological discussion**

As it happens in every economic analysis, this study rests on a number of debatable assumptions. The authors acknowledge that accounting for other databases of adaptation projects could mitigate this issue, but it would also enhance the risk of further double counting of costs given that different agencies may fund similar portfolios of projects. In a similar way, the
Investments have been estimated at 9.2 billion USD (in early stages of the adaptation process in developing countries. To our knowledge, this work constitutes the first systematic attempt to capture required investments associated with the understanding and planning of adaptation to be significant when compared with those of implementing infrastructure. Our estimates across 2015–2050 represent circa 7–10% of the 70–100 billion USD yr$^{-1}$ previously proposed for climate-proofing infrastructure (World Bank, 2010). This evidence was particularly strong when our estimates are compared with adaptation costs for infrastructure in water and agricultural sectors. In sectors where adaptation is typically very costly, like in case of the coastal sector, the estimates in this study represented between 5% and 15% of those required for adaptation via the implementation of protective infrastructure.

Although progress has been made regarding the amount of official financing available for adaptation in developing countries, our results point for the existence of deficits in the agricultural and forestry sectors. In these cases, it was noted that the available resources (in 2014) for developing countries fall short of the investments proposed in this study for financing the understanding and planning phases of adaptation. For other the water sector, total available resources for adaptation were found to surpass the estimated investments in this study in circa 11 billion USD.

Despite the acknowledged limitations, this work provides policy-makers with the first indication of the financial efforts associated with activities that are foundational for the successful implementation of cost-intensive infrastructure. Given the large costs involved in adapting to climate change (in the order of 100 billion USD yr$^{-1}$; World Bank, 2010), and given that that less tangible activities that increase the overall capacities of a country have been proposed to be the priority of adaptation (Fankhauser & Burton, 2011), this work provides a complementary view on adaptation investments in order to better inform those making strategic decisions.

Notes

1. http://www.pik-potsdam.de/cigrasp-2/.
2. In this paper we use the terms understanding and knowledge interchangeably. The first reflects the terminology from the framework this work borrows inspiration from; the second refers to terminology often used in economics and development fields.
3. https://gadm.org/data.html.

Disclosure statement

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