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**Leveraging public adaptation finance through urban land reclamation: cases from Germany, the Netherlands and the Maldives**

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**Abstract**
Flood risk in urban areas around the world is increasing due to socio-economic development and climate change. Urban climate adaptation measures are beneficial over the longer term, particularly in coastal areas, yet the upfront costs of such measures are significant. Moreover, public actors responsible for adaptation to flood risk face constrained budgets. A promising strategy for overcoming these constraints and enabling greater adaptation investment is land reclamation that includes adaptation, i.e. flood risk reduction. Land reclamation in high-value urban areas can generate substantial revenues through the sale or lease of new land, or taxes on increased economic activities, thus offsetting public adaptation investments. This paper explores the potential of land reclamation for leveraging public adaptation investments and associated distributional issues, by analysing 3 urban land reclamation and adaptation projects in Germany, the Netherlands and the the Maldives. We find that all projects have leveraging potential, and leveraging in projects primarily aimed at land creation is particularly high. Further, due to low adaptation costs needed to protect revenue streams in such projects, these investments appear to be 'low-regret'. Regarding distributional aspects, high project costs and limited public budgets for adaptation constrain public actors' ability to ensure equitable outcomes through planning instruments, for example, social housing. Further, in implementation, competition for project benefits can lead to further inequalities. We conclude that urban land reclamation presents a significant opportunity to leverage public adaptation investments under certain conditions. We further outline future research needs including to extend land-based financing theory from related urban infrastructure sectors to inform the design of equitable governance arrangements, and to better understand the role of such urban land reclamation projects in regional or national development pathways.

# 1. Introduction

Land reclamation, building upwards and into the sea, has a long history in areas with dense populations and a shortage of land such as around the southern North Sea and China. Globally, about 33,700 km2 of land has been gained from the sea during the last 30 years (about 50% more than has been lost), with the biggest gains due to land reclamation in places like Dubai, Singapore and China (Donchyts et al., 2016; Ma et al., 2014). In Shanghai alone, 590 km2 land has been reclaimed during the same period (Sengupta et al., 2018) and significant further land claim is expected in land scarce settings such as China, Japan and Singapore. Drivers of land reclamation around the world include growing urban populations, and infrastructure needs, such as airports or harbours (Li et al., 2014; Wang et al., 2014).

At the same time, coastal flood risk is increasing around the world due to sea-level rise and coastal development. Yet even though adaptation is found to be economically attractive, specifically in urban areas (Aerts et al., 2014; Hinkel et al., 2018; Lincke and Hinkel, 2018), many urban areas remain under-protected (Wong et al., 2014). On the one hand, this is due to the large upfront investments required for coastal adaptation, with benefits occurring stochastically in the future. On the other hand, public actors, traditionally responsible for coastal adaptation, face budget constraints and currently cover only a small share of coastal adaptation investments needed globally. These costs are estimated at roughly US$10 billion annually and projected to rise to US$70 billion annually by the end of the century (Hinkel et al., 2014). Indeed, recent austerity policies have meant public actors are struggling to maintain infrastructure investment levels, let alone provide the additional investments needed to close this coastal adaptation finance gap (OECD, 2015).

Against these backgrounds a promising way for overcoming financial barriers to coastal adaptation appears to be to combine coastal adaptation with land reclamation (Bisaro and Hinkel, 2018). Indeed, experiences with land reclamation in high-value urban areas show that significant revenues can be generated particularly for public actors (Phang and Helble, 2016; Wang et al., 2015). Moreover, the incremental cost of addressing adaptation when implementing major infrastructure projects is often small compared to total project costs (Hallegatte, 2009). Combining land reclamation with adaptation should therefore allow public actors to supplement scarce public funds for adaptation. By leveraging public funds in this way, greater investment in coastal adaptation can be enabled.

It should be noted that land reclamation is not the only measure that can generate revenues for adaptation. An emerging literature on 'value capture' explores the instruments through which public actors can recoup coastal flood risk investments from, e.g. beach nourishment investments (Mullin et al., 2018) or protection infrastructure (Druce et al., 2016). More broadly, land-value capture most well-established for transportation in the US and UK (Connolly and Wall, 2016), but increasingly applied in developing countries (Walters, 2012). However, scholarship has not yet addressed land-value capture for adaptation as applied to land reclamation.

Indeed, despite widespread and ongoing land reclamation throughout the world, and the apparent attractiveness of including coastal adaptation, there is little research on the role of land reclamation in climate adaptation strategies. Can land reclamation help to overcome the significant financial barriers to coastal adaptation? Further, what are the distributional implications of such projects for populations and societies exposed to flood risk? For instance, land reclamation mega-projects, such as the ongoing sea-wall in Jakarta (Sengutpa et al., 2018), are attractive to investors, and thus overcome financial barriers, precisely because they target exclusive real estate development. Exploring the distribution of benefits, and potential trade-offs, in such projects is therefore important for understanding the conditions required to achieve equitable adaptation.

This paper addresses these research gaps. Through a comparative study of land reclamation projects in the Maldives, Germany, and the Netherlands, we address the following research questions:

- How is adaptation delivered in land reclamation projects and through which mechanisms are public investments leveraged?
- To what extent do land reclamation and adaptation projects leverage public adaptation investments?
- What are the distributional effects of such projects on flood risk for existing land and population from an implementation perspective?

Comparing across the cases, we discuss conditions that have enabled land reclamation projects to achieve revenue generation and flood risk reduction, and thus adaptation win-wins (Hinkel et al. this issue). Finally, we discuss implications for future research, noting that the social conflicts that emerge in implementation of such large scale projects, and the role projects play in coastal development pathways need to be better understood.

# 2. Concepts and methods

## 2.1. Land reclamation technology

Land reclamation refers to reclaiming land from the sea in order to make it amenable to various human, e.g. residential or industrial, uses.

Land can be reclaimed for the sea through the following designs (Figure 1). *Land raising* involves land being reclaimed by filling land with pumped sand or other fill material or planting vegetation in order to support natural accretion of land. Land raising is thus a 'protection' strategy, addressing coastal flood risk by reducing the likelihood of a flood event. *Urban redevelopment* involves partially raising land and flood-proofing infrastructure and buildings. As such, it is an 'accommodation' strategy, addressing coastal flood risk reducing the impacts of a flooding event. Additionally, *polderisation* involves surrounding low areas with dikes. While historically an important measure, e.g. in the Netherlands or Bangladesh, our cases do not include polderisation, and therefore we do not consider it in detail here.

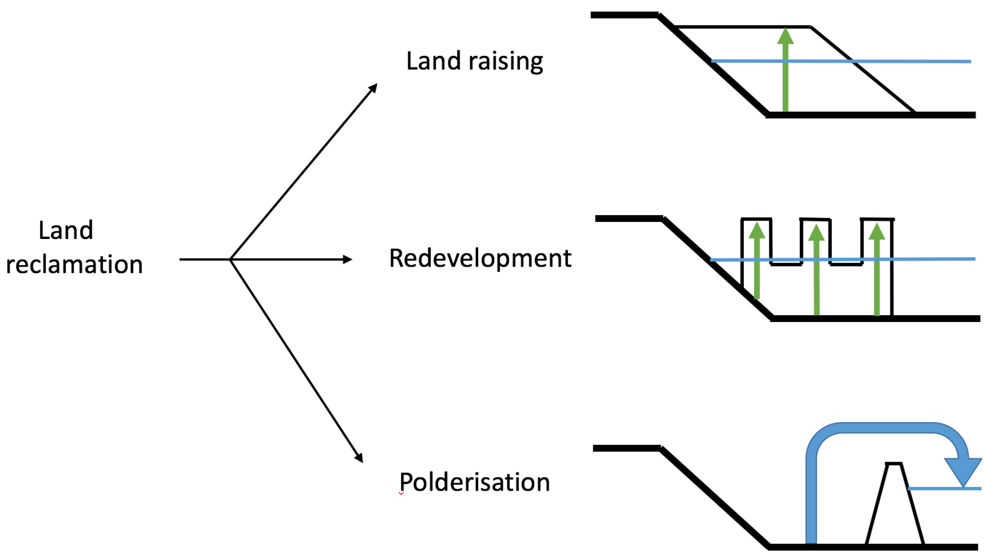


*Figure 1. Land reclamation technologies.*

## 2.2. The cost-benefit perspective on land reclamation

Land reclamation projects offer substantial opportunity for public actors to meet economic and adaptation goals because of potentially high-value benefits created and low project costs (Wang et al., 2014). Costs of land reclamation arise from flood risk reduction investments and infrastructure needed for real estate or industrial uses. Benefits of land reclamation and adaptation projects come from newly created and flood protected land.

Flood risk reduction costs are affected by land reclamation technology used, i.e. land raising (to protect or accommodate) or polderisation. Land raising involves material and transport costs for land fill. Generally, fuel costs for dredging ship operation dominate land raising costs, particularly when sand is available near the project site( Smith et al., 2007). If sand is not available nearby, local sand price is a further cost determinant. Sand cost varies by location, ranging between US$3 – 15 per cubic meter with some more costly locations in the UK or New Zealand (Linham and Nicholls, 2010). When sand is acquired from neighbouring countries, sand costs increase but remain a small share of overall costs, ca. 20-30% (UNEP, 2014). While these costs are thus currently low, increasing demand for sand has raised concerns about its scarcity (UNEP, 2014). Hard flood protection measures used for polderisation generally have higher unit costs than land raising (Jonkman et al., 2013). However, relative costs of flood protection measures for a given project are determined by local conditions, such as, land height and sand availability.

Infrastructure costs are generally greater than land raising costs, while remaining low compared to the costs of renting or purchasing existing urban land (MacKinnon et al., 2012). For real estate development, infrastructure costs include costs of road infrastructure, water and sanitation systems as well as social infrastructure needed to make an area attractive for residential use, e.g. hospitals, schools, and community centres.

Adaptation to sea-level rise gives rise to incremental costs for both flood protection and infrastructure (Fankhauser, 2010). Here, we define the incremental adaptation costs, as those investments needed to ensure a tolerable level of risk under climate change (Dow et al., 2013). This subjective measure based on stakeholder risk tolerance is useful for comparing perceived adaptation costs to the overall revenue generating potential of the project.

Regarding project benefits, we do not distinguish flood risk reduction benefits attributed to adaptation in particular from all project benefits, e.g. through developing a counterfactual flood risk reduction baseline of a hypothetical project developed without considering sea-level rise (SLR). There are two reasons for this. First, in practice, for most public actors this distinction is not salient because national or sub-national funding instruments for flood risk reduction generally do not distinguish between climate change and other biophysical drivers of flood hazard (Bisaro et al. 2019; Danielson et al. 2019). Exceptions are international adaptation finance instruments, particularly under the UNFCCC, e.g. the Green Climate Fund (GCF), where demonstrating that a project addresses climate change risk is a formal funding criteria (Green Climate Fund, 2015). However, this approach has been criticised as being driven by political considerations concerning the need to demonstrate the 'additionality' of adaptation finance (Schipper, 2006), unduly diverting attention from the other drivers of risk (O'Brien et al., 2007). Moreover, as we do not consider international adaptation finance arrangements, we do not take such an approach here.

Second, quantifying flood risk reduction benefits objectively, e.g. through SLR scenario analysis of future flood risk, is highly uncertain, as the benefits are materialised through real estate values and emerging evidence shows that coastal real estate markets tend not to reflect objective flood risks (Bin et al., 2011; McNamara and Keeler, 2013). Thus, higher levels of protection, above the tolerable risk threshold, would not necessarily be capitalised into real estate values (Beltrán et al., 2018). Instead, with the subjective approach to defining tolerable risk taken here, the projects analysed are assumed to meet a minimum standard of keeping risks at least tolerable under SLR over the lifetime of the measure.

In addition to benefit-cost considerations, public actors must also consider distributional effects (Kind et al., 2017). Equitable distributions are important both as a matter of social justice (O'Brien and Wolf, 2010), and because perceived fairness influences support for adaptation measures (Adger et al., 2016). Moreover, an emerging literature shows that investments in adaptation can exacerbate current risk distributions through, e.g. 'climate gentrification' (Keenan et al., 2018).

It is also important to note that land reclamation may also produce negative effects. Land reclamation may disrupt coastal ecosystems, negatively impacting coral reefs, mangroves or sea-grass beds (Al-Madany et al., 1991; Li et al., 2014), while also disrupting natural morphological processes, leading to coastal erosion and increased flood risk (Murray et al., 2014). .

Finally, in addition to the cost-benefit perspective on individual projects, we note that whether a project contributes to adaptation also depends in many settings on a project's wider regional or national development context. Major urban development projects may 'lock-in' a development pathway that brings more people and assets into the floodplain, compared to alternative pathways 'avoiding' floodplain development. Thus, a project may on its own reduce flood risk compared to a similar project without an adaptation component, but nonetheless increase risks over the long-term if high-end SLR scenarios materialise. However, whether a given pathway is unsustainable or "maladaptive" (Barnett and O'Neill, 2010) over the long-term is difficult to assess, given high SLR uncertainties (Wong et al., 2014). Further, it should be noted that divergence between low and high-end SLR scenarios is only expected after 2050, with greater divergences occurring after 2100 (Hinkel et al., 2019). Urban infrastructure lifetimes are generally short enough to allow some flexibility as more SLR information becomes available, thus mitigating 'lock-in' risks. Nonetheless, given the large populations and high asset values at stake, better understanding of the influence of major urban development projects on coastal development pathways can inform decision-making under deep uncertainties that characterise long-term coastal development decisions (Haasnoot et al., 2012).

We explore this issue in the analysis below, noting however that the salience of coastal development lock-in in our cases is low, due to limited availability of alternative development pathways that reduce coastal exposure either because of lack of non-coastal land, e.g. Maldives, Netherlands, or because of existing urbanisation trends, e.g. Hamburg (see Section 4.5).

In summary, while this paper focuses on public finance leveraging potential of such projects, we emphasise that careful consideration of the ecological and long-term impacts of land reclamation, in the context of regional development pathways, must also be integrated into public decision-making (Magnan et al., 2016).

## 2.3. The public finance perspective on coastal adaptation

The public finance perspective differs from the benefit-cost perspective. Here, the salient question is: what will the impact of the project on the public budget be? Actual cash flows are at issue, rather than cost and benefits. From this perspective, public actors are interested in leveraging their adaptation investments due to their limited budgets. We define leveraging public adaptation as investments in projects that achieve adaptation (i.e. flood risk reduction), while reducing net public expenditures, compared to a baseline project in which the public actor covers all costs and does not generate revenues.

Leveraging public investment in land reclamation projects can be achieved through several mechanisms. First, leveraging can occur through public actors generating revenue directly by selling new land or existing land that has experienced flood risk reduction due to the project.

Second, leveraging can occur indirectly through tax revenue generation. Tax revenues may be project-specific, e.g. flood protection levies, or general, e.g. property taxes or good and services taxes on assets or activities affected by the land reclamation project.

Third, leveraging can occur through externalising adaptation costs. For example, purchasers of newly reclaimed land may be required to carry out flood protection measures on their property. Successful cost externalization requires that the asset in question remains attractive to the purchaser even when they are required to carry out adaptation measures.

# 3. Methods and materials

## 3.1. Case selection and study limitations

Selection of cases addressing our research questions were based on several criteria established through desk review or expert interviews (see Supplementary materials). We first identified land reclamation and adaptation projects initiated by a public actor, producing a positive net present value and reducing flood risk. From these, only projects generating market revenues were selected. The market revenue generation model is currently prevalent worldwide in land reclamation (Sengupta et al., 2018), and is potentially a large source of revenue for public actors (Petersen, 2007), particularly in developing country contexts where tax collection is difficult (Suzuki et al. 2015). Yet it also poses risks for exacerbating inequalities (Shatkin, 2016). Exploring its relevance for coastal adaptation was deemed of high interest because, first, financial barriers are often the main barriers to coastal adaptation (Hinkel et al., 2018), and second, because market revenue generation models can potentially exacerbate existing inequalities undermining international climate policy objectives to protect the most vulnerable (UNFCCC, 1992)

Our analysis consisted in document analysis and data pooling from publicly available sources to establish the leveraging mechanisms, and cost and revenue streams in each case. We then conducted semi-structure interviews with key stakeholders to deepen understanding of key factors influencing adaptation costs, leveraging potential and distributional aspects, both in planning and implementation of projects (See Supplementary Materials). In particular, these interviews helped to identify distributional issues in project implementation.

In terms of limitations, we selected only projects in which adaptation considering SLR was included. This was necessary given our exploratory research questions aimed at describing how adaptation is delivered and leveraging mechanisms in land reclamation projects. However, this limits the insights generated on explanatory questions regarding the role of adaptation measures in producing revenue streams. Addressing such questions would also require ‘negative’ cases, i.e. without an adaptation component. This is may be taken up future research as discussed in Section 5.

Another limitation of the study is that the projects are not all complete; though the infrastructure component is complete in all three cases, real estate development at the time of data collection was either ongoing (HafenCity, Hulhumalé) or not yet underway (Nijmegen). Thus, our analysis of project revenues is based on projections collected from planning documents and interviews, and must be treated with caution. Similarly, for distributional outcomes, our analysis is based on planning documents, and expert interviews regarding the implementation processes, yet significant implementation lies in the future. Nonetheless, our analysis sheds light on how competition for project benefits plays out in practice in initial project phases, highlighting future research and policy priorities to address these issues.

## 3.2. Cases

### *3.2.1. Hulhumalé, the Maldives*

The Maldives is a country of around 1200 low-lying atoll islands in the Indian Ocean, with a population of ca. 430,000. Land scarcity is a major concern in the Maldives. Malé, the largest urban centre (pop. 135,000), with a population density over 39,000 inhabitants per $km^2$, is expected to continue growing due both to population growth and increasing urbanisation (Speelman, 2015). Further, the Maldives are threatened by sea-level rise, as island elevation is on average just 1.5m above mean sea-level (MSL). The Maldivian atolls provide opportunity for reclaiming new islands because of their shallow depths and the proximity of abundant sediment needed for land fill (MEE, 2015). Raising new islands to sufficient height provides valuable new land at a greater flood safety standard than existing islands.

A major land reclamation project, raising the new island of Hulhumalé, was initiated by the Government of the Maldives in 1997 to address land scarcity. Located near Malé, the project currently provides an additional 2 $km^2$ of urban land, with 7 $km^2$ planned by 2040 (Magnan et al., 2016). Hulhumalé is raised 2.1m above MSL, 0.6m higher than the average height in Malé. Phase I (1997-2004) reclaimed 185 ha for predominantly residential uses, and includes infrastructure, such as roads, schools and mosques. Phase II (2006-2016) reclaimed an additional 240 ha also for predominantly residential uses. The first land plots in Phase II were on sale for real estate development in November, 2016. The government's stated goal is for Phase II to reserve 30% of residential use areas for social housing (GoM, 2008).

### *3.2.2. HafenCity, Hamburg*

Hamburg (pop. 1.8 million) is a major German North Sea port city in the Elbe river estuary. The city is well-protected from flooding as the main city dikes to were increased to 7.5 m above mean sea level (MSL) following damages during a major storm surge (+6.5m) in 1962 (von Storch et al., 2008). They were increased again in 2012 to between 8.0m and 9.3m above MSL to account for, among other considerations, sea-level rise of 0.6m this century (Bürgerschaft, 2012).

Following German reunification in 1990, the HafenCity port and industrial area, located outside of the city dike, was seen as attractive area for redevelopment. High value urban land is scarce in Hamburg, and redevelopment provided an opportunity for Hamburg to position itself as a global city.

The City of Hamburg embarked on the HafenCity project in 1997, re-developing 155 ha of industrial and port area outside the main Hamburg city dikes, of which ca. 88 ha were owned by the city. The project will provide 127 ha of land area for mixed use development foreseeing up to 7,000 new residential units for 14,000 residents and commercial units by 2030. The project expands the inner city centre area by around 40%, while providing the same level of flood protection as the main Hamburg city dike (HafenCity, 2017).

With the project area only 4.5m above MSL, an innovative flood risk reduction concept was needed to achieve the flood safety standard (Restemeyer et al., 2015). Rather than building conventional dikes or flood barriers, HafenCity followed an 'accommodation' approach, raising individual land plots by ca. 3.0m to between 7.5m and 9m above MSL. Residential building ground floors are occupied by parking garages or commercial use, rather than residential units to further reduce flood risk. Further, critical roads and public transport infrastructure connecting the project to the city have been raised to between 7.5m and 8.3m above current MSL to ensure residents are not cut-off during flood events.

### *3.2.3. Room-for-the-River, Nijmegen*

The Room-for-the-River Programme commits €2.2 billion (2008-2017) from the Netherland's Delta Fund for increasing robustness of fluvial flood protection infrastructure and improvement of environmental conditions. The Programme's rationale is that continuous dike heightening alone is not a sustainable long-term flood risk solution both because of technical constraints, and because dike heightening can negatively impact ecosystem services in river areas (Ruimte voor de Rivier, 2008). Room-for-the-River funded 34 projects that met the nationally prescribed flood safety standard by widening and deepening the riverbed, thus providing an alternative flood defence measure that also created co-benefits of improved environmental quality.

At Nijmegen on the Waal River, where the flood safety standard ranges from an annual flooding probability of 1:10.000 to 1:40.000, a solution was sought for a river bottleneck, as the existing dike no longer met the flood risk standard. Rather than a conventional upgrade, the Room-for-the-River project relocated the existing dike, widening the riverbed and reducing the gradient of through-flow creating a new river channel and urban island, "Veur-Lent". The island is a prime recreational and residential location.

The project's primary objective is to meet the flood safety standard, which is calculated considering climate change out to 2100. It is thus an adaptation project that includes land reclamation. Widening the river reduces flood risk by decreasing high water levels, and thus the design height for dikes required by the flood safety standard. The project achieved a 34cm decrease in gradient at design high water levels, and thus reduced dike reinforcement needs and increased the robustness of associated flood protection infrastructure. 170,000 inhabitants of Nijmegen experience a protection increase from 1:1000 to 1:30,000 annual flood probability level, while the project also increases protection for properties behind adjacent dike stretches (estimated 21.000 people) (Kind and van der Doef, 2012). The indirect effects are due to increased land area at an acceptable flood safety level, i.e. the newly created island, which provides 210 new houses (ca. 600 people) protected to the 1:30,000 year annual flood probability level. Thus, an estimated 191,600 people benefit from increased protection.

# 4. Results

## 4.1. Leveraging mechanisms

Table 1 summaries the cases, showing the primary economic goals and project types, associated leveraging mechanisms and scale in terms of number of protected people.

| Case | Primary economic goal | Project type | Leveraging mechanism | | | # of people protected | Stage of implementation |
|---|---|---|---|---|---|---|---|
| | | | **Market revenue** | **Tax revenue** | **Cost external-ising** | | |
| Hulhumalé, Maldives | Providing more urban land | Raising new land | Lease and sale of reclaimed land | Real estate transaction tax | - | 146,000 | Phase I complete. Phase II reclamation complete, infra ongoing. |
| HafenCity, Hamburg | Providing more urban land for prestige developments | Raising and redevelop-ment of existing land | Sale of redeveloped land | Real estate transaction tax; Land value tax | Private builders required to raise buildings. | 12,600 | 30% of land redevelopment completed including sale. |
| Lent-Nijmegen, Netherlands | Meeting flood protection standard through nature based approach | Raising new land and protecting existing land | Sale of redeveloped land | Land value tax | - | 191,600 | Flood risk reduction infrastructure complete. Land not yet sold. |

*Table 1. Cases: land reclamation projects and leveraging mechanisms.*

Table 2 summarises the financial perspective (see Section 2.3), showing costs, revenues and leveraging ratio across all three projects (see Supplementary materials for the calculations). In contrast to the standard cost-benefit approach, financial benefits, i.e. discounted revenue streams, are assessed rather than economic benefits. All project revenues are considered to be associated with the adaptation measures, as described above.

All three cases exhibit leveraging mechanisms through both direct market revenue (land sale or lease) and indirect tax revenue generation (see Table 1). In Hulhumalé, the principle leveraging mechanism is direct revenue from land lease for private real estate development. Tax revenues – from acquisition fees between US$50,000-$100,000 for land plots in Hulhumalé (HDC, 2017), and a business profit tax of 15% – are smaller than market revenues, but still significant.

In HafenCity, a principle leveraging mechanism is also direct revenue from land sale. The city-owned land (88 ha) is sold to private developers following infrastructure and site preparation investments. Tax revenues – generated from real estate transactions (4.5%), property tax, and a general taxes on good and services – are nearly as significant as market revenues in HafenCity. This reflects the projected increased tourist activities due to the project – and thus the importance of the image presented by the HafenCity project.

In Nijmegen, land sale also provides some leveraging, as market revenues are generated by the municipality selling reclaimed land to developers. The real estate development project ‘De Waalsprong’ foresees 210 new houses built on Veur-Lent. Yet the principle mechanism is tax revenue generated from tourist arrivals, based on the improved natural setting for recreation delivered by the project. Tax revenues are generated from real estate transaction taxes, increased land value taxes, and value added taxes on increased economic activity resulting from the project.

Only in HafenCity is leveraging is achieved through externalising adaptation costs, as private real estate developers are responsible for raising new buildings to 7.5-9m above MSL on land they purchase.

| | A: Investment costs (mil) | B: Incremental adaptation costs (mil) | C: Cost externalisation | D: Revenue (PV, mil) | | | | (C+D)-A: Net public expenditure (mil) | (C+D)/B: Leverage ratio | # people flood protected |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Market | One-time tax | Recurring tax | Total | | | |
| Hulhumalé | $192 | $16.1 [Raising island additional 0.6m] | n/a | $830 | $15 | $111 | $956 | - $764 | 5940% | 146,000 |
| HafenCity | €3000 | €54 [Raising transport infrastructure and buildings by ca. 4.0m] | €7 [Private developers raising land] | €865 | €38.9 | €838.4 | $1742.3 | €1257.7 | 3240% | 12,600 |
| Lent-Nijmegen | €358 | €352 [Full project costs excl. real estate site prep.] | n/a | €8.8 | €0.6 | €36 | €45.4 | €318.6 | 12.9% | 191,600 |

*Table 2: Comparing project costs, revenues and flood protection. PV: present value at project completion.*

## 4.2. Adaptation costs

Adaptation costs differ as a share of the overall projects costs in the different cases. Whereas for Hulhumalé and HafenCity, adaptation costs are less than 10% of the overall costs, for Nijmegen they make up nearly the entire project costs. In the Maldives, adaptation costs of US$16.1 million are incurred solely for raising land an additional 0.6m above protection levels at Malé to reduce risk from long-term sea-level rise (MEE, 2015). In HafenCity, incremental adaptation costs, estimated at €54 million, include raising existing road and transport infrastructure, as well as raising of individual land plots, needed to manage flood risk in HafenCity's 'accommodation' approach. In Nijmegen, because the project primarily addresses flood risk reduction, incremental adaptation costs of €352 million are nearly the full project costs, including raising new land, relocating the dike and retrofitting existing infrastructure, e.g. roads, to meet the national flood safety standard (See Supplementary materials for cost calculations).

Adaptation costs in the projects differ for two main reasons. First, differences in how adaptation is delivered influence adaptation costs. In HafenCity, adaptation is delivered through an "accommodation" approach, whereby flood risk reduction involves limiting damages during flood events by raising buildings and disallowing ground floor residential occupancy. In Nijmegen and Hulhumalé, in contrast, adaptation is delivered via "protection". Whereas in Nijmegen protection is delivered by retrofitting existing infrastructure, including the dikes, in Hulhumalé a new island is created. While extending or redeveloping existing land often requires costly infrastructure retrofitting, e.g. HafenCity and Nijmegen, raising new land does not require infrastructure retrofitting, and thus adaptation costs can be relatively low.

Second, the projects' diverse aims also influence adaptation costs. Projects that primarily aim to increase housing availability, often incur lower adaptation costs as share of the overall project, than those whose primary aim is to provide flood risk reduction. However, we note that project costs are also largely driven by context specific factors, e.g., proximity and type of available sediment, shoreline slope, etc. Therefore, we do not wish to generalise, but rather indicate which project types may lead to more significant adaptation costs in a given location.

## 4.3. Leveraging potential

We observe large differences in leveraging potential across the three cases. Table 2 shows leveraging ratios for the projects, which are calculated as the ratio of leverage generated (i.e. revenue generated or cost externalised) to incremental adaptation costs. Generally, the leverage ratio shows that in land reclamation projects that include adaptation, the incremental costs of adaptation are small compared to potential revenues. In particular, the leveraging ratio of Hulhumalé is extremely high (5940%), while also providing a net profit (i.e. negative net expenditure) to the government. This illustrates the high potential profitability of land reclamation in settings of land scarcity and sediment availability, while also illustrating the small costs of adaptation to protect profits over the long-term. In HafenCity, similarly, a very high leveraging ratio is achieved (3240%), however the project appears to be a net loss for the City, which is inline with other reports on HafenCity finances (Menzel, 2010). As the negative balance sheet impact of the project is driven by several high-cost and non-flood risk related infrastructure investments, the case also illustrates that the incremental adaptation costs are small compared to potential revenue streams. Thus, adaptation investment is an attractive investment for public actors in land reclamation projects from a cash flow perspective.

For adaptation projects that include land reclamation, i.e. Nijmegen, the leveraging ratio is much less (12.9%), however, still significant. Interestingly, in Nijmegen, the significant revenue stream comes from taxing recreational activities on the new land, rather than land sales. This illustrates that different leveraging mechanisms are available in land reclamation projects, and these can capture significant value created by public investments (Petersen, 2007).

## 4.4. Distributional effects

Distributional effects can be analysed along two dimensions: the distribution of adaptation benefits, i.e. flood risk reduction, and the distribution of economic (co-)benefits, i.e. newly created land value. In this section, we analyse distributional issues that arise in project planning, while in Section 5, we discuss distributional issues that emerge implementation.

For projects that only create new land, e.g. Hulhumalé and HafenCity, without reducing flood risk on adjacent areas, adaptation benefits are produced indirectly by creating new flood protected living area that can reduce the overall flood risk exposure, when people move from high risk areas to the newly created lower risk areas. In such cases, the distributional question revolves around who has access to new land, as this entails both adaptation benefits and economic benefits. Exclusion of poorer segments of society from such new land may occur as public infrastructure investments lead to increased in property values and rents, so-called “climate gentrification” (Kennan et al. 2018).

Equitable access to the benefits of such land reclamation protection depend on the instruments through which the government provides access to the land. As the leveraging mechanisms in both Hulhumalé and HafenCity depend on the sale or lease of a significant portion of land for high-end real estate, this limits the extent of social housing is included in planning.

For Hulhumalé, land value is high compared to project costs, so that significant social housing was included (65% for Phase I and II combined), while still maintaining high profitability. All of Phase I and 30% of residential development in Phase II was dedicated to social housing. Yet while prices of social housing units are below market price for the greater Male area (NBS, 2014), they are high as a share of Maldivian US$8600 per capita GDP (World Bank, 2018). From a planning perspective, lower income households access to affordable housing in the project is thus somewhat limited.

In HafenCity, in contrast, project costs are high in relation to the amount of land reclaimed, as significant investment was required for flood proof transport infrastructure, as well as for prestige or other investments, such as the Elbphilharmonie and HafenCity University (Menzel, 2010). Further, the City of Hamburg's stated aim to limit net expenditures in the project, and fund its infrastructure investments through profits from land sale, further constrains the inclusion of social housing. The overall proportion of non-market housing in the project is relatively low at 10% (HafenCity, 2017).

In both cases, actual access to land, even through social housing instruments, also depends on additional factors, such as, intransparent or costly application procedures, and access to credit (MNBS, 2012). We discuss these implementation issues in greater detail below (Section 5.2).

In projects that incorporate land reclamation into adaptation addressing a wider area, i.e. Nijmegen, adaptation and economic benefits may be provided through different channels. In terms of adaptation benefits, Nijmegen achieves the most equitable distribution, as adaptation is provided as a public good. Flood risk reduction is provided through river widening and dike relocation, and all current residents benefit from the attain for the flood safety norm in Dutch law (van der Most et al., 2014).

Economic benefits in Nijmegen are partly provided as a public good, i.e. improved recreational opportunities on reclaimed land, and thus distribution is relatively equitable. Moreover, the significant leveraging mechanism is tax generated from additional private consumption, i.e. restaurant or hotel patronage. Thus, as the Nijmegen project does not depend mainly on land sale to generate revenues, significant social housing (40% of the development) is included (pers. comm., van Ginkel. 2017).

### 4.5. Contextualising project benefits

As mentioned in Section 2.2, the broader development pathway to which a project contributes should be considered in order to account for 'lock-in' risks over the long-term. This issue is particularly relevant when alternative development pathways could 'avoid' risks, e.g. by developing urban infrastructure outside of the coastal floodplain. For our three cases, however, such alternative development pathways are limited.

In Hulhumalé and Nijmegen, the biophysical setting limits the viability of development pathways that avoid coastal risk. The Maldives' islands lie approximately 1.5 m above mean sea-level (MSL) at safety levels generally lower than those at Malé and Hulhumalé (MEE, 2015). As Hulhumalé will be populated by Maldivians migrating from either Malé (which is experiencing land scarcity as noted above) or peripheral islands (MNES, 2012), at 2.1 meters above MSL, it will reduce flood risk of the Maldivian population in aggregate. Moreover, with no other higher land, the option of 'avoiding' coastal risk within the Maldives does not exist. In Nijmegen, a similar argument applies, as around 70% of the population of the Netherlands live in the flood plain, and this is expected to grow with urbanisation (Kok et al., 2008), making 'avoiding' coastal development within the Netherlands less viable.

For HafenCity, Hamburg's population has increased over several decades, with population growth rate being greater in the 10 years preceding HafenCity, than in the 20 years since implementation began (Statistisches Bundesamt, 2019), providing some limited evidence that the project has not increased urbanisation that has been occurring anyway. In the context of such urbanisation, the project thus contributes to coastal adaptation by increasing urban flood-proofed land. Over the very long-term, i.e. beyond 2100, however greater consideration of the lifetime of project investments, and their influence on the flexibility (or lack thereof) of coastal development pathways is needed, which goes beyond the scope of our analysis here.

## 5. Discussion

### 5.1. The 'win-win' potential of land reclamation and coastal adaptation

Several insights arise out of the comparative analysis presented above. First, land reclamation appears to be attractive for financing coastal adaptation, under particular conditions, and should be given greater attention by countries, regions and cities, planning coastal development in the context of sea-level rise. In particular, land reclamation can best be considered part of a viable adaptation pathway, when alternative development pathways outside of the coastal floodplain are constrained either for biophysical reasons, e.g. lack of available non-coastal land, or socio-economic reasons, e.g. lack of comparable areas of economic opportunity outside of the coastal zone. That said, it must be emphasised that our analysis here provides only an argument for considering land reclamation as an adaptation option, particularly where financial constraints are a main barrier, and a comprehensive project appraisal would need to take full account of environmental impacts, e.g. impacts on coral reefs or other ecosystems, as well.

Second, complementary to the first point, when a country, region or city has decided to undertake a land reclamation project, adaptation should be included because it is relatively low-cost, and thus low regret. Coastal development is often driven by urbanisation processes, e.g. demand for greater economic opportunities in cities (Ciccone and Hall, 1993), and where coastal cities exist, viable alternative development pathways outside the coastal zone may be limited. Given these constraints, the search for 'win-win' solutions, i.e. in which climate adaptation and economic goals are achieved simultaneously, are promising for addressing coastal flood risk under sea-level rise (Hinkel et al., this issue). Land reclamation that includes adaptation is potentially such a 'win-win' solution.

Third, in all types of land reclamation projects, i.e. either aimed primarily at urban development or primarily at adaptation, governments should deploy planning and governance instruments to ensure equitable outcomes. This is important because the revenue generation model needed for leveraging public investments presents a number of risks (discussed below) for exacerbating existing inequalities and thus failing to reduce risks for the most vulnerable and undermining the notion of a 'win-win' solution.

## 5.2. Implementation: competition for project benefits

One major risk regarding ensuring equitable distributions is that land values must be high enough in a project area to raise sufficient funds for adaptation. This implies that land reclamation projects will tend to only be implemented in rich areas with poor areas receiving less investment. While this is an important point, we note that this issue is inherent to any type of adaptation measure, e.g. building dikes or beach nourishment, that relies on value capture as a means of finance (Mullin et al., 2018), as well as for funding public infrastructure more broadly (Connolly and Wall, 2016; Suzuki et al., 2015). Governments implementing land reclamation and adaptation projects must account for this tendency, and ensure that distributional issues are addressed through redistributing funds raised in such projects to fund adaptation in poorer areas, where projects based on revenue generation are not feasible.

Other risks to equitable distributions emerge from the political economy, for example, in competition for benefits, e.g. social housing leases, once projects are implemented (Sovacool et al., 2015). In implementation, the actual distributional outcomes realised may differ substantially from those aimed at in planning measures. The financial analysis above shows that, in planning, trade-offs between providing flood protected land and equitable outcomes may not exist, depending on project and local conditions. For projects with low adaptation costs and high land values, e.g. Hulhumalé, the government can use social housing to ensure equitable access to benefits. However, high value coastal properties provide incentives for private actors to engage in rent-seeking behaviour, e.g. to acquire control of social housing (Storbjörk and Hedrén, 2011) and these incentives are stronger in a weak enforcement environment (Beatley, 2012), vulnerable to corruption (Suzuki et al., 2015). Further, some barriers to social housing access, e.g. registration and other official documentation requirements, may fall disproportionally on the poor (Anguelovski et al., 2018).

Our cases in which implementation is underway, Hulhumalé and HafenCity, provide evidence for the emergence of these dynamics in accessing project benefits. In Hulhumalé, an illicit rental market of social housing units in Hulhumalé has emerged, as individuals with other housing in the greater Male area have illegally acquired social housing units and sublet them (MNBS, 2012). Regulations against these practices have not been strictly enforced, restricting the access for the poor by increasing the value of and competition for social housing units (Aujaz, pers. comm. 2018). Further, the government plan for all Phase I residential units to be social housing has been changed, as around 200 social housing units leases were auctioned in 2018 (Aslam, personal comm., 2018).

In HafenCity, while around 10% residential units are allocated to social housing, due to the project's attractive central waterfront location, it is largely occupied by high earners and with among the highest average rents in the city (Menzel, 2010; Menzl, 2011). Further, the general trend is towards increases in rental and sale prices as more individual buildings in the project are completed (Menzl, 2011). Moreover, even non-market housing arrangements are more expensive than in other parts of the city, as high transaction costs for the tendering process and adaptation requirements have constrained housing co-operatives in keeping rents low, and pushed developments further towards the high-end market (Fellmer, personal comm., 2017).

### 5.3. Implications for future research

Given the high leveraging and revenue generation potential of projects, a first area of future research concerns the distributional effects of adaptation projects, based on revenue generation and value capture instruments, which our cases showed pose risks for exacerbating inequalities both in planning and implementation. Research in closely related areas of transportation infrastructure and urban development in which land-based financing is being applied has developed theory explaining distributional outcomes through political economy dimensions that shape planning decisions, e.g. autonomy of state land managers (Shatkin, 2016), economic significance of the real estate sector (Shatkin, 2008), and legitimising discourses (Harman et al., 2015). It has also developed theory on factors positively influencing efficiency and effectiveness in implementation, e.g. strong property tax law and land tenure systems (Walters, 2012) land market maturity, and public administrative capacities (Norregaard, 2013). As coastal adaptation shares public good characteristics with urban development or transportation infrastructure sectors, but differs from them in that coastal adaptation benefits are stochastic and long-term, existing theory could be applied and extended to account for these differences. Such research could advance understanding of incentives facing public and private actors at different levels regarding land reclamation in the context of SLR, in order to support the development policy instruments enabling adaptation and housing affordability. Methodologically, this requires a broader sample of cases than examined here, i.e. including cases with no adaptation (negative cases).

A second area of future research concerns distinguishing situations in which future coastal development is unavoidable, and thus land reclamation can play a beneficial role in an "advance the line" adaptation strategy, and from situations in which less intensive coastal development is possible, and thus an adaptation strategy of "avoid" may be preferable. Such research would aim to construct plausible development pathways and involves the transformations communities to understand the actors, networks, and narratives that influence transformational change needed for such alternative development pathways (Tàbara et al., 2019). From an analytical point of view, research on scenario development to establish credible adaptation and development baselines with which to appraise land reclamation projects and their effects on coastal exposure is needed to better understand both the project-level and long-term effects of such projects on coastal risks (Watkiss, 2015). Indeed, this salient both to identify "lock-in" risks, as well as, potential trade-offs that can emerge when pursuing alternative strategies to greater coastal development because reducing assets in the coastal floodplain – an 'avoid' strategy – also implies reducing housing availability and potentially housing affordability. If SLR is on the low-end of current projections, coastal cities could experience marginal increases in flood risk, but high property prices because of lack of investment. This presents yet another channel of "climate gentrification" (Keenan et al. 2018), and should be explored further.

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