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Abstract

This explorative qualitative study utilised the IPCC categories of adaptation opportunities and constraints as a framework to understand the barriers and enablers to the development and uptake of contextually relevant climate-resilient water management technology in three sub-Saharan African cities. In-depth interviews were undertaken with interviewees from the research, government and civil society sectors to gain insight into perceived opportunities and constraints to the development, uptake and market dissemination of such technology in Blantyre, Harare and Gaborone. The majority of the identified opportunities and constraints aligned well with the global IPCC categories; while certain IPCC categories were found not to be relevant to the study. Two new categories of adaptation opportunities and constraints were discovered, i.e. did not fit within an IPCC category; they were an opportunity: 'climate change windows of opportunity', and a constraint: 'ethics and intellectual property'. Our results indicated that the nuances of the Global South context are often not well-considered in the design of climate-resilient water management technology, and that a number of constraints detract from the development, uptake and dissemination thereof. There are however opportunities inherent to sub-Saharan African cities which could be capitalised on to stimulate the development, uptake and dissemination of locally designed or modified water technology. We discuss new frontiers for exploration of this topic by way of conclusion.

Keywords	Climate change adaptation; opportunities; constraints; sub-Saharan Africa; water management; technology

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The Editorial Board
Global Environmental Change
Per email
05 March 2018

ICLEI - Local Governments for Sustainability
Knowledge Park III, Century City
Cape Town, South Africa

Dear Prof Barnet, Dr. Lebel, Prof New and Prof Seto

RE: SUBMISSION OF RESEARCH ARTICLE TO GLOBAL ENVIRONMENTAL CHANGE

We have pleasure in submitting an original research article entitled "*exploring the opportunities and constraints to the development of locally applicable water management technology in three sub-Saharan African cities*" for consideration by Global Environmental Change. We confirm that this work is original and has not been published elsewhere, nor is it currently under consideration for publication elsewhere. We have no conflicts of interest to disclose.

In this paper, we adopt a qualitative approach to explore opportunities and constraints to the development, uptake and market dissemination of climate-resilient water management technology in the context of three cities in sub-Saharan Africa (SSA) through the lens of the Intergovernmental Panel on Climate Change (IPCC) categories of adaptation opportunities and constraints. We suggest that the nuances of the SSA urban context are seldom considered in the design and implementation of water supply and treatment technology in these areas, and that uptake of innovative water supply and treatment technology is hindered by a number of constraints in the cities of Blantyre (Malawi), Harare (Zimbabwe) and Gaborone (Botswana). We also suggest that there are a number of opportunities inherent to the context of these cities that could be harnessed to improve development, uptake and dissemination of new or modified climate-resilient water technology. Significantly, two inductively derived categories of opportunity and constraint emerged from our study, namely the constraint of 'ethics and intellectual property' and the opportunity signified by 'climate change windows of opportunity'. These categories did not fit within the IPCC framework, but were emphasised by interviewees in the government, research and civil society sectors as important factors.

We believe that this manuscript is appropriate for publication by Global Environmental Change because it provides insight into (among others) the social, cultural, economic and political drivers that hinder or promote the development and uptake of important technology that has the potential to strengthen urban resilience and adaptation efforts in the region. This is of importance to a region that faces rapid environmental, social and socio-economic change due to a changing and uncertain climate, as well as high rates of economic growth and urbanisation. We strive to advance knowledge on these drivers by suggesting implications thereof for the IPCC categories in SSA cities, as well as proposing new frontiers for exploration and further research.

Thank you for your consideration of this manuscript.

Sincerely,

Luke Moore
Senior Professional Officer

ICLEI - Local Governments for Sustainability is the leading global network of over 1,500 cities, towns and regions committed to building a sustainable urban future.

By helping the ICLEI Network to become sustainable, low-carbon, ecomobile, resilient, biodiverse, resource-efficient, healthy and happy, with a green economy and smart infrastructure, we impact over 25% of the global urban population.

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Exploring the opportunities and constraints to the development of locally applicable water management technology in three sub-Saharan African cities

Keywords: climate change adaptation, opportunities, constraints, sub-Saharan Africa, water management, technology

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Abstract

This explorative qualitative study utilised the IPCC categories of adaptation opportunities and constraints as a framework to understand the barriers and enablers to the development and uptake of contextually relevant climate-resilient water management technology in three sub-Saharan African cities. In-depth interviews were undertaken with interviewees from the research, government and civil society sectors to gain insight into perceived opportunities and constraints to the development, uptake and market dissemination of such technology in Blantyre, Harare and Gaborone. The majority of the identified opportunities and constraints aligned well with the global IPCC categories; while certain IPCC categories were found not to be relevant to the study. Two new categories of adaptation opportunities and constraints were discovered, i.e. did not fit within an IPCC category; they were an opportunity: 'climate change windows of opportunity', and a constraint: 'ethics and intellectual property'. Our results indicated that the nuances of the Global South context are often not well-considered in the design of climate-resilient water management technology, and that a number of constraints detract from the development, uptake and dissemination thereof. There are however opportunities inherent to sub-Saharan African cities which could be capitalised on to stimulate the development, uptake and dissemination of locally designed or modified water technology. We discuss new frontiers for exploration of this topic by way of conclusion.

1. INTRODUCTION

In addition to biophysical factors such as water scarcity and projected increases in future temperature, socio-economic contexts influence water management systems and practice (Biazin et al, 2012; Rahaman and Varis, 2005; Niemczynowich, 1999), and thus also shape the development and uptake of water management technologies. Where African cities are growing rapidly, urban leaders are faced with the need to provide services and infrastructure for expanding areas and a growing number of citizens (Parnell & Pieterse, 2014). Growth, coupled with the unequal distribution of infrastructure and services resulting from segregationist practices of colonial times (Nilsson, 2017), and the growing prevalence of informal urban form (Watson, 2008), makes for a complex water management and governance context in sub-Saharan African cities.

Technologies—pieces of equipment or techniques for performing a particular activity—have the potential to enhance the resilience of water management systems and practice, and thus reduce the climate vulnerability of a city (Allwood et al, 2014). This study explores adaptation opportunities and constraints related to the development and uptake of climate resilient water management technology in the sub-Saharan African cities of Blantyre (Malawi), Harare (Zimbabwe) and Gaborone (Botswana). This study had an additional focus on the uptake of locally developed or modified climate resilient water management technologies specifically, recognising the benefits of locally developed or modified technology, such as being better adapted to the local context and complexity, while at the same time creating livelihood and development opportunities for local urbanites.

The study was motivated by an identified need for enhanced resilience of the water management practices in each city under an uncertain climate future, as established through ongoing research relationships. In addition, there is a lack of literature on opportunities and constraints to climate-resilient water management technologies in these cities. Through insights shared by stakeholders from across government, research and civil society in the three cities, locally perceived opportunities and constraints were conveyed in relation to the IPCC's adaptation constraints and opportunities framework. By applying a framework developed for global applicability within the sub-Saharan African context, we were able to suggest some implications for IPCC framework categories in relation to sub-Saharan African cities, and some new frontiers for exploration emerged. It is recognised that three cities do not represent the sub-Saharan African city context in its entirety, but this study provides

exploratory insight into the nuances present in the African climate-resilient water management technology space.

1.1. Blantyre, Harare and Gaborone: local water management contexts

With its many climatic zones, cultures, languages and religions, there is no one Africa (Parnell and Pieterse, 2014). As such, the local water management contexts in Blantyre, Harare and Gaborone are diverse.

The World Health Organisation (WHO) and United Nations International Children's Emergency Fund (UNICEF) jointly track global data on drinking water, sanitation and hygiene at national and regional levels. For Malawi, the most recent WHO/UNICEF data indicates that 67 per cent of rural persons had access to basic safe drinking water in 2015; while 87 per cent of urban dwellers had access to basic safe drinking water at this time (WHO & UNICEF, 2017). From a governance perspective in Malawi, local governments are mandated to plan and coordinate water and sanitation programmes, and in Blantyre an independent entity, the Blantyre Water Board, is responsible for the city's water supply (Maoulidi, 2013). The city is located at 1000 meters above sea level and is far from its water sources: the Shire River, Walker's Ferry and Mudi dams (Maoulidi, 2013). This means that water supply to Blantyre is costly, as water has to be pumped vertically and over a great distance (Maoulidi, 2013). Water service delivery in Blantyre is complex, and great disparities exist in terms of household water access. In low-income areas potable water supply is erratic (Maoulidi, 2013), and residents rely on a combination of water kiosks (stalls for the sale of water), communal taps and unreliable sources such as shallow wells, streams and drainage ditches (Maoulidi, 2013). The use of pit latrines, deforestation, brick moulding and mining leads to the pollution of shallow wells, streams and drainage ditches (Dalitso Mpoola et al, 2011), exposing residents to substantial health risks.

According to the WHO and UNICEF (2017), Botswana's rural population was characterised by 58 per cent access to basic safe drinking water in 2015; while 95 per cent of the country's urban dwellers had access to basic safe drinking water at this time. In Gaborone, the urban landscape differs from that of Blantyre, with individual houses on large plots being the predominant form of housing (Kent & Ikgopoleng, 2011). Water supply largely relies on surface water, through a system of nine dams (Palm Johansson & Andersson, 2015). However, this supply is insufficient, resulting in the importing of water from the Molatedi

Dam in South Africa in order to meet demand. The Water Utilities Corporation, a government owned entity, is responsible for water supply and waste water treatment in Gaborone, as well as in the other larger cities in Botswana (Palm Johansson & Andersson, 2015).

Zimbabwe's urban population had relatively good access to basic safe drinking water at 94 per cent in 2015, but only 53 per cent of rural dwellers had access to the same at that time (WHO & UNICEF, 2017). Zimbabwe's capital, Harare, is home to major industrial areas and national government's administration offices, and is relatively better developed than other parts of the country (Parliament of Zimbabwe, 2011). However, with high urbanisation rates, growth of informal settlements, aging infrastructure and high levels of water pollution, access to clean and safe water is a challenge (UNRCO, UNCT & Office of the President and Cabinet, 2014). The government owned entity, the Zimbabwean National Water Authority (ZINWA), is responsible for the country's water resource management (ZINWA, 2017), and rehabilitation and upgrades to water and sewer infrastructure, together with the development of new water sources, all of which are national priorities (Zimbabwe Independent, 2016).

Within their different contexts all three cities, Blantyre, Gaborone and Harare, are facing challenges in terms of the provision of safe, consistent and equal access to water for all their citizens, particularly surrounding rural and peripheral urban communities. Pockets of information on the use of climate-resilient water management technologies in these cities can be found if searching across the climate change adaptation, water management and urban planning literature. However, a more consolidated picture of locally contextualised opportunities and constraints related to the development and uptake of locally developed or modified climate-resilient water management technologies in these cities, is lacking.

2. METHOD

Many scholars have developed frameworks to better understand the opportunities — factors that make it easier to plan and implement adaptation actions, that expand adaptation options, or that provide ancillary co-benefits — and constraints — factors that make it harder to plan and implement adaptation actions (Klein et al, 2014) — that operate in relation to climate change adaptation (e.g. Jones, 2010; Moser & Ekstrom, 2010; Adger, Arnell & Tompkins, 2005). The Intergovernmental Panel on Climate Change (IPCC) drew on many of these frameworks, to develop the typology outlined in Table 1. This typology built iteratively on preceding assessment reports, and therefore represents an evolving understanding of these

concepts; the IPCC's typology was thus used in a qualitative manner as a lens to frame this study. It should be noted that matching responses from interviewees with the IPCC categories was fundamentally a subjective process, as boundaries between categories can be subtle (Shackleton et al, 2015), in line with the qualitative nature of this study.

Table 1: The IPCC's typology of opportunities and constraints (derived from Klein et al, 2014)

IPCC Category	IPCC definition/example
Economic constraints	The entitlements of actors to economic resources and by larger macro-level driving forces such as economic development and trends in globalisation.
Financial constraints	Adaptation strategies and options can be constrained by access to financial capital.
Governance & institutional constraints	Adaptation constraints associated with governance, institutional arrangements, and legal and regulatory issues.
Human resources constraints	Human resources as one of the factors influencing adaptive capacity, e.g. ability to provide the foundation for intelligence gathering, the uptake and use of technology.
Knowledge, awareness & technology constraints	Significant knowledge gaps and impediments to flows of information that can constrain adaptation, but knowledge in itself is not sufficient to drive adaptive response.
Physical constraints	The capacity of human and natural systems to adapt to a changing climate is linked to characteristics of the physical environment including the climate itself.
Biological constraints	Behavioural, physiological, and genetic tolerances of individuals, populations, and communities to climate change and extremes.

IPCC Category	IPCC definition/example
Cross-scale dynamics	Adaptation processes can be constrained by interactions and dynamics within or among different scales.
Social & cultural constraints	Social and cultural factors that are linked to societal values, worldviews, and cultural norms and behaviours.
Constraints & competing values	Differential values of societal actors and the trade-offs associated with prioritizing and implementing adaptation options.
Awareness raising opportunities	Positive stakeholder engagement, communication of risk and uncertainty, participatory research.
Capacity building opportunities	Research, data, education, and training; extensions services for agriculture; resource provision.
Innovation opportunities	Technological change; infrastructure efficiencies; digital/mobile telecommunications.
Learning opportunities	Experience with climate vulnerability and disaster risk; learning-by-doing; monitoring and evaluation.
Policy opportunities	Integrated resource and infrastructure planning; spatial planning; design/planning standards.
Tools opportunities	Risk analysis, vulnerability assessment, multi-criteria analysis, decision-support systems.

2.1. Data collection

This exploratory research made use of the nonprobability method of snowball or referral sampling, whereby potential interviewees are identified by requesting that initial interviewees

suggest other people who might be interested in participating in the study or who exhibit the key characteristics that may meet the study aim (Forman & Damschroder, 2015; Trotter, 2012; Babbie, 2004). Existing relationships and contacts were leveraged to identify additional interviewees who could add insight into specific issues, such as their knowledge of local entrepreneurs in the water technology space.

Climate change adaptation has been described as a complex and multidimensional issue that manifests at a range of scales and involves a range of actors from state and non-state sectors (Koch et al, 2007). Thus the notion of a societal 'sector' has useful application "*for organizing adaptation efforts and aligning information and actions to stakeholder groups, economic indicators, or jurisdictional elements*" (Ernst & Preston, 2017, pg. 38). Potential interviewees were identified from the research and local government sectors based on existing project or research relationships. Given the focus of the research on constraints and opportunities to the development and uptake of locally developed or locally modified climate-resilient water management technology, a third sector in the form of civil society, which was likely to yield entrepreneurs that were engaged in developing or adapting these solutions, was included. The rationale for this approach was that these three sectors are the most active in the water-climate-innovation nexus and thus had the potential to provide insight into matters aligned with the research topic from different perspectives.

Primary data collection was undertaken by posing open-ended questions to interviewees. Open-ended questions are well suited to a qualitative study, as they seek to highlight thought processes, beliefs and perception in the most neutral way, i.e. with as little guidance and influence from the researcher as possible (Barriball and While, 1994). Once interviewees had been identified, contacted and consent for study participation obtained, 27 semi-structured interviews (see Table 2) consisting of 10 open-ended questions were undertaken in Blantyre, Harare and Gaborone. The sample size is within the range of 20-30 interviews recommended for qualitative studies of this nature (Marshall, Cardon, Podder & Fontenot, 2013).

Table 2: Distribution of interview interviewees by sector and location

Sector	Definition	Blantyre	Harare	Gaborone	Total
Government	Government officials whose mandate included at least one of the following functions: water, sanitation, environment, climate change, and/ or planning.	4	2	2	8
Research	Researchers (e.g. academic staff) whose research interests were aligned with water governance and management, water technology, and/ or climate change adaptation.	4	2	6	12
Civil society	Individuals or organisations whose activities were aligned with local entrepreneurship in the fields of climate change adaptation and/ or water governance, management and innovation.	4	3	0	7

Key themes covered during the interviews were: (a) the interviewee's understanding of climate change and its effects on their city-region; (b) whether they thought technology and knowledge have a role to play in dealing with climate change impacts; (c) whether they knew of local entrepreneurs that have developed local and/ or small scale solutions that would improve water management and/ or supply; and (d) what constraints and opportunities they had identified in relation to the development and uptake of contextually relevant climate-resilient water management technology.

2.2. Data analysis

Qualitative content analysis seeks to interpret textual data's content using a classification process called 'coding' to identify themes and patterns in a systematic manner (Hsieh & Shannon, 2005; Elo & Kyngäs, 2008). Within qualitative content analysis, the coding process can adopt either deductive or inductive reasoning approaches; where deductive codes are developed from existing theories or concepts (*a priori*); and inductive codes are developed from the data itself (Forman & Damschroder, 2015). Data analysis for this research started with deductively developed codes in the form of the IPCC categories of adaptation opportunities and constraints (Table 1). Given that a purely deductive or *a priori* approach can constrain data analysis (Bazeley & Jackson, 2013), this research made allowance for the emergence of new categories or codes that were garnered inductively or *in vivo* as the analysis proceeded.

A 'code and retrieve' process was undertaken by means of computer-assisted qualitative data analysis, which has become an established tool for researchers working within the broader qualitative content analysis framework (Flick et al, 2014), and was used as a point of departure for analysis of primary data. Each of the 27 interviews were uploaded into the *Nvivo* qualitative data analysis software package for coding and further analysis. In order to allow for cross-case analysis, a 'framework matrix' with interview cases in rows and themes in columns (Bazeley & Jackson, 2013) was created within *Nvivo*. The framework matrix juxtaposed the IPCC subcategories of adaptation opportunities and constraints as columns with coded phrases, sentences and statements from interview transcriptions as rows, which were identified by the researcher as being aligned to or fitting within the IPCC subcategories of opportunities and constraints. The researcher was also open to the possibility of *in vivo* opportunities and constraints being discovered, when text coded did not fit well within the IPCC typology (Table 1), following discussion with the broader research team. This approach is aligned with calls for further investigation on hidden or under-researched adaptation barriers or constraints (Shackleton et al 2015). These *in vivo* categories were also added to the framework matrix. A supplementary quantitative tool in the form of an *Nvivo* 'codebook' was also incorporated into the analysis to provide secondary insight into the density, spread and spatial distribution of the respective sub-categories of opportunities and constraints by highlighting the number of times each category was cited by interviewees, as well as the number of interviewees who referred to each category. Such an integrated approach can increase the effectiveness and reliability of qualitative studies by enhancing the strengths and reducing the weaknesses associated with

purely qualitative or purely quantitative approaches (Buchecker, Hinziker, & Kienast, 2003; Trotter, 2012).

3. RESULTS AND DISCUSSION

In their synthesis study of the barriers to climate change adaptation in sub-Saharan Africa, Shackleton et al (2015) note that certain barriers (or constraints) are relatively intuitive, and are easily categorised, while others are more nuanced and as such more difficult to categorise. Constraints that fall into the latter cohort often include social, cultural, economic and political factors, and tend to be omitted or mis-categorised as they are "*socially constructed and highly subjective, contingent on individual and community knowledge, personal and societal values, perceptions of risk and loss, and power structures*" (Adger et al, 2009, cited in Shackleton et al, 2015, pg. 3). The same holds true for this research; certain IPCC categories were immediately obvious within the data, whereas other categories were more ambiguous and led to discussion within the research team as to how best to code the text. Importantly, no statement or phrase was assigned to more than one category, but was categorised where the researcher judged was the best fit.

A consequence of treating categories of opportunities and constraints as mutually exclusive is that fewer instances of individual opportunities or constraints were coded than would be the case if statements were coded to multiple categories. When combined with the sample size of this study, it means that this study was not attempting to produce results that can be generalised for sub-Saharan African cities, or even the three cities where data was gathered, we however explored an important research topic, and our results aim to stimulate important conversations and galvanise future research. Babbie (2004, pg. 372) notes that such an approach is not unusual for a qualitative study, the strength of which lies in "*revealing insights, rather than arriving at conclusions based on statistical analyses of large populations*", while Marshall (1996, pg. 524) notes with respect to qualitative studies that "*improved understanding of complex human issues is more important than generalisability of results*".

Figure 1 summarises the spread of adaptation constraints coded, while Table 3 summarises the spatial and sectoral distribution of adaptation constraints. Within Figure 1 and 2, 'references' refers to the number of times each category was coded, while 'sources' refers to the number of interviewees who cited that particularly category as a constraint.

In Gaborone, no interviewees from the civil society sector were interviewed, due to a seeming lack of civil society organisations organised around water or climate change issues, a scenario which was confirmed by local researchers. This may be due to: (a) the lack of demand for such organisations or civic groups on the basis of alignment of state and civil society objectives and a mutually cooperative relationship (Dipholo & Tshishonga, 2013); and/or (b) a civic environment not conducive to the formation of such groups (Mogalakwe & Sebudubudu, 2006). Further research may shed light on this particular situation.

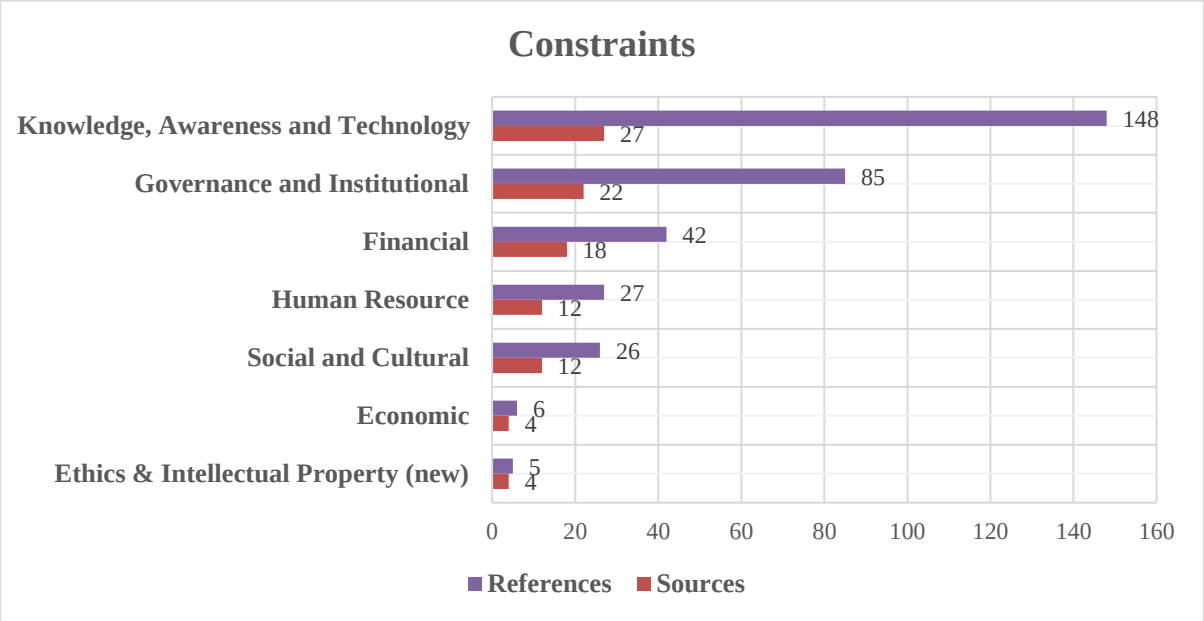


Figure 1: Summary of adaptation constraints by reference and source

Table 3: Overview of spatial and sectoral trends of IPCC typology of constraints

IPCC category	Spatial trend			Sectoral trend		
	Blantyre	**Harare**	**Gaborone**	**Research**	**Civil society**	**Government**
Knowledge, awareness & technology constraints	✓	✓	✓	✓	✓	✓
Physical constraints	×	×	×	×	×	×

IPCC category	Spatial trend			Sectoral trend		
Biological constraints	×	×	×	×	×	×
Economic constraints	✓	✓	✓	✓	✓	✓
Financial constraints	✓	✓	×	✓	✓	×
Human resources constraints	✓	×	✓	✓	✓	✓
Social & cultural constraints	✓	✓	✓	✓	✓	✓
Governance & institutional constraints	✓	✓	✓	✓	✓	×
Constraints & competing values	×	×	×	×	×	×
Cross-scale dynamics	×	×	×	×	×	×

3.1. Constraints found in all three cities and sectors

From a qualitative perspective, constraints that emerged in all three locations and across all three sectors related predominantly to the IPCC categories of: (a) economic constraints; (b) financial constraints; (c) knowledge, awareness and technology constraints; and (d) social and cultural constraints. These are unpacked below.

3.1.1. Economic constraints

Our study found macro level issues related predominantly to the lack of an enabling economic policy environment that would encourage the development and uptake of locally developed water technology. More specifically, the absence of economic incentives such as import waivers for technology components and the lack of downstream or upstream value chains for

water technology were seen as significant constraints to innovation and entrepreneurship in the water technology sphere. An interviewee from a technology-focused research organisation in Gaborone elaborated further by noting that economic challenges can hinder the development of technology prototypes and discourage funders who might otherwise be willing to take them to production and market: "*for this (technology) to get to the ordinary person, you are talking about a gap where someone has to be able to manufacture this. And unless we get either government to step in to fill that gap, which in most cases tends to be inefficient, we need to have someone, who would be able to take his technology and turn it into manufactured products*." The reliance on hydropower was identified by a research interviewee in Blantyre as a significant economic constraint, particularly during dry periods when the co-dependency of water supply and electricity often results in energy shortages that negatively affect grid-powered water technology. Such macro-level driving forces could be seen as economic constraints that make it hard to develop and ensure uptake of locally developed climate resilient water management technologies.

3.1.2. Financial constraints

Financial constraints were differentiated from economic constraints on the basis of scale, i.e. financial issues were understood to refer to more micro level or localised issues, while macro level issues were coded under economic constraints. Craft, Gama and Thinley (2017, p.22) listed limited funding as one of three primary "*barriers and challenges to accessing climate finance for technology development and transfer*". Similarly, we found the most common financial constraint related to the unaffordability of currently available water technology to the average consumer. The research sector in Blantyre put forward the risk-averse nature of finance institutions who may avoid funding innovative (and therefore largely untested) ideas as a specific constraint. A similar finding relates to the misalignment of water innovation and technology investment costs and the accrual of actual benefits or return on investment, which Kiparsky et al (2013) put forward as a financial constraint to the development and uptake of water management technology. Likewise, the scale of the concepts/ innovations/ ideas proposed by researchers or entrepreneurs was seen to be misaligned with the availability of financial resources dedicated to supporting innovation or higher-risk investments to the point of mass production and market rollout. The priorities of funding institutions were also seen as being focused elsewhere; as it was noted that funding institutions may not view water technologies as an immediate revenue earner. A research sector interviewee in Gaborone

indicated that the way in which technology is presented to funding institutions is a constraint in the sense that researchers or technologists may lack the necessary financial background to make a strong business case for investment in their technology.

Access to state-backed financial resources was seen as being constrained by lack of political interest in climate-resilient water technology within the research sector in Gaborone. Albeit in a developed country context, Tàbara, St. Clair and Hermansen (2017) reached similar conclusions in Spain, where interviewed stakeholders believed that the relevance and influence of climate change concerns in politics was very low. With respect to institutional affiliation, an interviewee from the civil society sector in Harare noted "*you have to be an institution or find a private person or on your own personal level [to access funding]*", implying that individual entrepreneurs are disadvantaged in this respect.

3.1.3. Knowledge, awareness and technology constraints

Lack of knowledge or information is regularly cited as a constraint to climate change adaptation (Ernst & Preston, 2017; Shackleton et al, 2015). Tàbara et al (2017) note that contemporary knowledge production and communication processes that predominantly advocate the production of 'more knowledge' about climate impacts, has proved inadequate in terms of understanding the complexity of the climate change phenomenon, specifically its impact on society. Knowledge, awareness and technology constraints were emergent in all three locations and sectors; it must be noted that specific questions on knowledge and technology were put to interviewees, which may have contributed to the pervasiveness of responses related to this IPCC category (see Table 1 and Figure 1). Nonetheless, cross-cutting findings related to general knowledge and awareness deficiencies related to climate change impacts and causes, and knowledge on what constitutes appropriate or contextually relevant water technology. On the latter point, Shackleton et al (2015) note that barriers to adaptation are almost always context-specific, which would appear to have particular applicability to technology types and contexts.

Similarly, Koch et al (2007) and Craft et al (2017) cite lack of awareness, capacity and poor information flow as key constraints to adaptation and accessing climate finance. More specific findings from the government and research sectors of Harare and Blantyre relate to the marginalisation of indigenous knowledge in favour of 'formal' or scientific knowledge systems relating to land management, water use and water governance. An interviewee from Harare

noted that as a child he knew that wetland areas were off-limits for agriculture and development, but that this is no longer the case. Tàbara et al (2017) allude to this issue in emphasising the need for 'social translation' of climate knowledge, while Koch et al (2007) note that a range of authors have demonstrated the importance of local knowledge and value systems. Similarly, the 'packaging' of knowledge on climate change for a narrow audience was perceived as a constraint in the research sector in Gaborone. Ernst and Preston (2017) suggest that the knowledge tools at the disposal of the research community have not been effectively delivered or 'translated' in a way that non-research knowledge recipients can use the knowledge to guide adaptation efforts.

Constraints related broadly to technology emerged from all three locations and sectors as technology deficiencies in terms of: water harvesting methods and technology; context-specific/ appropriate technologies (see Koch et al, 2017 on 'suitable' technologies) for a Global South context; low-water and wastewater reuse technology; and renewable energy powered or off-grid water technology. These deficiencies are supported by the assertion of Tàbara et al (2017) and Smith and Smithers (1997, cited in Koch et al, 2007) that conventional approaches to climate knowledge development and distribution have largely not addressed local contexts.

3.1.4. Social and cultural adaptation constraints

We found social and cultural adaptation constraints to be spatially and sectorally cross-cutting, with one interviewee identifying the issue of over-reliance on the provision of aid or donor funding for climate change work, and the possibility that donor funding may discourage innovation, as need and motivation may be reduced by the provision of aid. Worldviews and cultural-traditional factors such as differentiated access to resources on the basis of gender in recipient communities were also seen as constraints to the development and acceptance of water technology. Constraints in the form of poor fit with local contexts or practices, such as the local grazing systems and land-tenure systems, can constrain the uptake of water technology, not Biazin et al (2012). Where interventions are implemented without regard to social and cultural context, the risk of rejection is raised, and the association of certain types of technology as 'technology of the poor' can occur (de Bruin et al, 2015).

3.2. Constraints prevalent in specific cities and/ or sectors

3.2.1. Governance and institutional constraints

Constraints related to governance and institutional factors focused on the issues associated with a centralised or government controlled water governance system, and more general issues related to the regulatory framework and institutional mandates and performance of officials. The former issue was seen as a significant constraint in all three locations, but was raised by only the research and civil society sectors. Centralised water governance systems were seen as a market constraint to entrepreneurs developing local technology, as government often plays the role of a gatekeeper in the space. In contrast to this situation, Tàbara et al (2017) point to the crucial role that 'boundary organisations' - organisations that mediate relations and broker knowledge between science and policy (Gustafsson & Lidskog, 2017) - can play in supporting the integration of climate change adaptation strategies into decision-making and capacity building. An interviewee from the civil society sector in Harare felt that government's reticence to adopt a *laizzez faire* approach to technology and entrepreneurship in the water treatment and supply sector had its roots in the fact that many such initiatives are backed by foreign donor funding, and that allowing foreign donors access to such a fundamental basic need was not politically expedient. Dipholo and Tshishonga (2013, pg. 58) highlight similar sentiments that were expressed by the government of Botswana, saying that certain non-governmental organisations (NGOs) "*encroach on the well-being as well as the independent identity of the developing world through rigid and self-serving interpretations of what supposedly constitutes international norms*".

An interviewee from the research sector in Blantyre felt that with the resultant lack of government financial support, local entrepreneurs are forced to seek alternative sources of funding which means they are often bound to donor's terms and conditions that can be restrictive of contextually relevant innovation and upscaling. The view of a civil society interviewee in Harare was that government was using pre-payment for water to 'over commodify' the provision of water to communities as opposed to considering water as a basic right, and without addressing more fundamental issues such as the maintenance of infrastructure.

Governance constraints relating to regulation and institutional frameworks focused on poor coordination, not only inter-departmentally (such as between the water treatment and supply

departments), but also inter-sectorally, where a lack of coordination between research institutions and decision-makers in governments was cited as a particular constraint. Similarly Ernst and Preston (2017) note that governance constraints such as the fragmentation and disorganisation of institutions is often cited as an adaptation constraint that manifests in regional, local, and institutional contexts.

Civil society representatives in Blantyre cited factors such as the prohibitive costs of business licenses, taxation and restrictive local government by-laws as a constraint to entrepreneurs upscaling their ideas or reaching full operationalisation and market uptake of their technology. A interviewee from the government sector in Harare highlighted historical or inherited challenges as a governance constraint, such as water infrastructure inherited from the colonial era not being adequate to meet current demand - "*what happened in Harare was that infrastructure was inherited from the colonial era...boreholes were being drilled at each and every residence. Water was supplied to urban water users in an effort to cope with water which was not enough*."

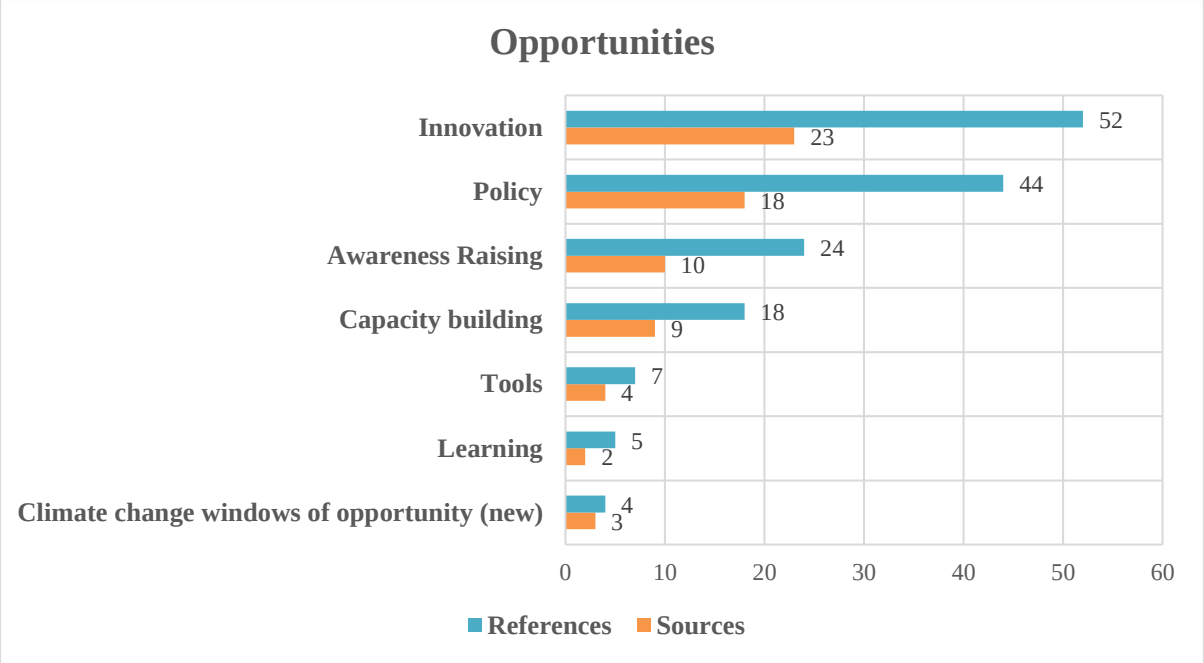
3.2.2. Human resource constraints

Constraints related to human resources were found to manifest mainly in Blantyre and Gaborone, and in all three sectors. Constraints coded under this category were defined as a lack of personnel with specialised and transferable skills. At the community level, a civil society interviewee from Blantyre felt that a lack of capacity from a technical skills perspective at the household level in relation to basic water related issues such as treatment and safe storage was a constraint. Similarly, a government sector interviewee from Blantyre was of the opinion that local communities lack the necessary human resources to meaningfully contribute to water project design and implementation. It is worth noting that in some cases, stakeholders may have the required human resources to contribute to adaptation initiatives, but that they do not always use this capacity (Koch *et al* 2007). Entrepreneurs were seen to be constrained by a deficiency of expertise in marketing by a research sector interviewee in Blantyre, who saw this as a key skill. Similarly, personnel in government and academic institutions were seen to lack crucial business training and skills. The lack of in-house capacity in government departments and the subsequent use of external parties for strategic planning was seen by Kiparsky et al (2013) as a further factor that could hinder innovation in their study of hindrances to urban water innovation in the United States.

Kiparsky et al (2013) found that public water entities often lack in-house capacity, and this human resource constraint has frequently led to the hiring of consulting engineers. Furthermore, the fact that public entities, and the decision-makers working within that space, have very limited ability to take financial risk is a major institutional constraint. Such governance and institutional constraints indicate the need for institutional innovation to go hand in hand with technological innovation (Kiparsky et al, 2013).

3.3. Opportunities found in all three cities and sectors

Klein et al (2014) describe how innovation opportunities in the climate change adaptation space can unlock resources that were previously not available to stakeholders. Opportunities (Figure 2 and Table 4) related to innovation included technological change that made use of context-appropriate technology, particularly renewable energy powered or decentralised energy solutions to power water supply or treatment technology. Policy opportunities included political and financial support for entrepreneurs and researchers from local government, such as subsidies for innovative technology or technology components and strategies to reduce 'government monopoly' or control of the water supply and management sector. In a similar vein, Klein et al (2014) note that policy change can result in a variety of adaptation opportunities, including the reduction of the impact of climate change and increased adaptive capacity (Hertel & Rosch, 2010, cited in Klein et al, 2014), while Spires and Shackleton (2017) highlight the existence of conducive institutional environments as a key enabler or opportunity for pro-poor climate change adaptation in South Africa.



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393 **Figure 2: Summary of the spread of adaptation opportunities by reference and source**

394 **Table 4: Overview of spatial and sectoral trends of IPCC typology of opportunities**

IPCC category	Spatial trend			Sectoral trend		
	Blantyre	Harare	Gaborone	Research	Civil society	Government
Awareness raising opportunities	✓	✓	✓	✓	×	✓
Capacity building opportunities	✓	×	✓	✓	✓	×
Innovation opportunities	✓	✓	✓	✓	✓	✓
Learning opportunities	✓	×	✓	✓	×	✓
Policy opportunities	✓	✓	✓	✓	✓	✓

Tools opportunities	✓	✓	×	✓	✓	×

3.4. Opportunities prevalent in specific cities and/ or sectors

Awareness raising opportunities were coded in all three locations and in the research and government sectors. Interviewees noted that community initiatives & awareness campaigns related to climate change adaptation initiatives exist, and that opportunities to coordinate and implement them are similarly present. There was a perceived opportunity for entrepreneurs to capitalise on water's status as a basic need in terms of scope, interest and investment in water management technologies. Klein et al (2014, pg. 902) note with very high confidence that the enhancement of climate change awareness "*can help build individual and institutional capacity for adaptation planning and implementation*".

Capacity building opportunities were discussed by interviewees from the research and civil society sectors of Blantyre and Gaborone. In keeping with the IPCC nomenclature with respect to examples of capacity building, resource provision opportunities identified related to the development of communal water distribution and treatment centres, while research opportunities were identified around the nexus of sustainable waste management, local community actions, and sustainable land management. The readiness/ willingness of people to be capacitated and receive new and more sustainable water technology was identified as a further opportunity under this category. Pasquini et al (2015) also found capacity building to be an adaptation opportunity, citing the prospect to train and develop capacity as a key factor in authorities being able to integrate climate change action into their management plans and policies.

Learning opportunities were discussed by researchers and government officials in Gaborone and Blantyre, and included the use of networks between researchers to disseminate and share knowledge internationally which could lead to cross-border transfer of technology, as well as capitalising on work that existing research institutions conduct, particularly those that have the mandate to focus on the creation of new technologies to stimulate innovation (e.g. Chinhoyi University of Technology, just outside Harare). Learning opportunities based on cooperation and networks have the potential to create opportunities, with networks of overlapping and complementary expertise required for the development and implementation of new technological solutions (Kiparsky et al 2013). Adaptation opportunities related to *tools* were

discussed by research and civil society representatives in Blantyre and Harare, and related to tools such as methods to co-produce knowledge and other participatory approaches, as well as the use of social media as a potential decision support tool to disseminate information on water technology and climate change adaptation. Klein et al (2014) highlight the ability of decision-support tools to assist with prioritisation of climate change action, an important opportunity in this regard.

3.5. Inductively derived categories

It became clear that the addition of a new categories of constraints and opportunities were necessary as findings began to emerge inductively from the research (Table 5). Present both sectorally and spatially was the issue of a lack of trust between civil society and government, where the latter were seen as not respecting intellectual property rights related to the development of innovative technology or initiatives. We termed this category: 'ethics and intellectual property constraints' (see Figure 1 and Table 5). There is consensus in the literature that inadequate protection of intellectual property rights adversely affects innovation, particularly in developing countries (Papageorgiadis & Sharma, 2016; Kim, Lee, Park & Choo, 2012; Chen & Puttitanun, 2005).

Table 5: Spatial and sectoral overview of new categories of opportunities and constraints

New category	Spatial trend			Sectoral trend		
	Blantyre	Harare	Gaborone	Research	Civil society	Government
Ethics & intellectual property constraints	×	✓	✓	✓	✓	✓
Climate change windows of opportunity	✓	✓	✓	✓	×	✓

Within our study, a civil society interviewee noted that entrepreneurs had unsuccessfully approached government for institutional and financial support for a particular initiative, only

to discover that the initiative had been taken forward as a government initiative: "*most entrepreneurs…would think twice, you know. They will try by all means to get [private] funding before they approach government with any project because they will take it over… people have lost on very good projects*." This constraint hinders the development and upscaling of water technology and leads to entrepreneurs seeking alternative sources of funding and dissemination, as well as exacerbating cooperation challenges with government. It is perhaps unsurprising to expect a constraint such as this to emerge from the civil society and/ or research sector, but the issue was also mentioned by a government interviewee. In Harare, the *ethics and intellectual property constraint* was emphasised by both researchers and civil society interviewees, with a civil society interviewee saying: "*many projects and ideas have been given to government by entrepreneurs that have been turned down, but then the project or idea is activated a couple of months later, coming in as a government project, with little or no recourse for the originator*". Interestingly, interviewees from Blantyre did not mention the *ethics and intellectual property constraint*, which may imply that engagement between government and developers of technology has been more positive, and would explain why we found a greater number of organised civil society and researcher groups working on water management technology in Blantyre. One example is Water for People-Malawi that works in peri-urban Blantyre (Water for People, 2017), and another is the water, sanitation, health and appropriate technology development (WASHTED) unit at the University of Malawi (University of Malawi, 2017).

A second inductively derived category, was that of 'climate change windows of opportunity' (see Figure 2 and Table 5), which found resonance with interviewees who felt that climate change could represent an opportunity. Researchers in Harare and Gaborone felt that the existence of the climate change phenomenon creates opportunities that would not exist in its absence, e.g. climate change as a catalyst for the development and uptake of new green technology, and/ or certain funding agencies incentivising/ promoting green technology such as 'climate-smart' water technology, that may not have been the case had climate change not made it imperative. In their study of the response of rural communities in Honduras to the impacts of extreme weather events, McSweeney and Coomes (2011) define the concept of climate change 'windows of opportunity' as a scenario "*in which abrupt environmental change may catalyse rural communities' latent adaptive capacities and stimulate systemic improvements"* (McSweeney & Coomes, 2011, pg. 5203). In their case, the window of opportunity provided by a significant climate disaster in the form of a major flood was used to

improve ecological sustainability and social resilience at the community level (McSweeney & Coomes, 2011). Similarly, Shackleton and Spires (2017) found that 'windows of opportunity' related to the increased awareness and profiling of climate change, often related to major events, like the Conference of the Parties (COPs) can be harnessed by local government officials to mobilise resources and initiate action that builds climate resilience.

4. IMPLICATIONS OF FINDINGS

4.1. Implications for the development and uptake of climate-resilient water management technology in Blantyre, Harare and Gaborone

Our exploratory research found that knowledge, awareness and technology constraints are significant barriers to the development and uptake of climate-resilient water management technology in the three cities (see Figure 1 and Table 3). To overcome this constraint requires up-skilling of stakeholders, related to human resource constraints in relation to climate change and what is possible in terms of innovative water management. Finding ways to not solely rely on the traditional mode of delivering water, which requires improved public sector funded service delivery, is imperative. Historical challenges (categorised as a governance and institutional constraint) such as past perceptions that service delivery is only for colonial imperialists (Gafar, 2017), and the inheritance of under-developed infrastructure and economies that focused on exports aimed at supplying unfinished goods to developed countries (Wengraf, 2016), will only be overcome when solutions are garnered from all segments of society.

Based on our research, it is proposed that the following three steps are important in overcoming constraints to the development and uptake of climate-resilient water technology: (1) Up-skilling, encouraging behaviour change and capacitating all sectors of society to engage in the climate change and water management space, which links to *awareness raising*, *capacity building* and *tools* opportunities; (2) once this capacitation has occurred, mechanisms need to be in place where innovative ideas (linked to *innovation opportunities*) can be brought, developed and tested, in a safe and trusted environment; and (3) that the economic and financial environment is such, that these ideas can be taken to scale.

The second step is reliant on improved coordination (related to *governance and institutional constraints*) across the various sectors engaged in water management, and may require more transformational approaches, such as re-thinking how water is supplied, and by whom, to move

away from the situation where as one interviewee said: "*it is only the water corporation that are allowed to sell water, so the market is basically closed to any entrepreneurs*". A policy solution highlighted by an interviewee was the development of a "*clear policy that defined the particular path to follow for entrepreneurs for their idea to be appreciated, funded and commercialised*". Seeking out alternative modes of supplying water to sub-Saharan African cities' burgeoning population is an important area of research; accordingly Ruiters and Matji (2016) developed a public-private partnership conceptual framework and models for how to finance improved water service infrastructure in South African municipalities. They found that public-private partnership models can play a key role in overcoming institutional challenges in local government. A learning opportunity identified in this research that will contribute to improved coordination and up-skilling, relates to the use of regional (e.g. SADC) networks to disseminate and share knowledge. Two such networks that can be built on to contribute to this opportunity within the water technology space, are WaterNet: a Southern and East African network of research institutes specialising in water, that aims to build regional institutional and human capacity in Integrated Water Resources Management (WaterNet, 2017), and the African Water and Sanitation Local Authorities (AWASLA) network: a local government focused network for knowledge exchange on water and sanitation issues in Africa (AWASLA, 2017). Furthermore, and related to coordination, is finding ways for researchers, civil society and government officials to work in a more collaborative fashion. In Harare, the Chinhoyi University of Technology has a major focus on the development of technological solutions to society's biggest challenges. The University has developed a number of water management technologies, but the uptake of these solutions by government (that has the explicit mandate to provide water to Harare's residents) has been slow.

The last step—taking the technology to scale—relates to the *economic and financial constraints* discussed, as Ruiters and Matji (2016, p. 291) state: "*access to finance is the lifeblood of water services infrastructure delivery*". Dealing with these constraints, would require finding ways to bring down the cost of import tariffs and technology components, as well as finding innovative means to either attract funders that are willing to fund un-tested technology, and/ or reducing the risk related to funding this technology by government assisting in the feasibility/ testing phases of product development. This links well to *'windows of opportunity'*, where for example, in another sub-Saharan African city—Cape Town—in response to the severe drought being experienced in 2017, the City approached civil society and the private sector to bring their ideas/ solutions to the city's attention, in the hope of

uncovering un-tapped innovative solutions that could be procured by the city and form part of the solution package in dealing with the crisis (eNCA, 2017). Interestingly, Gaborone interviewees did not mention financial constraints and this can be hypothesised to be due to the higher socio-economic status of Gaborone, versus Blantyre and Harare (represented by Botswana's GDP/ capita being 13 times higher than Malawi's and 9 times higher than Zimbabwe's [African Economic Outlook, 2016]).

Another important theme related to indigenous knowledge, in operation as: (a) a *knowledge, awareness and technology constraint* in relation to the marginalisation of indigenous knowledge in favour of 'formal'/ scientific knowledge systems; (b) a *capacity building opportunity*, i.e. the need to integrate indigenous and scientific knowledge on water treatment; and (c) a *policy opportunity*, i.e. the need to integrate indigenous knowledge into relevant policy processes. These references relate to how indigenous knowledge has much to offer in terms of progressing the discourse on water management technology, however it was also highlighted (under *social and cultural constraints*) that traditional beliefs can hinder the acceptance of new/ different technology even if beneficial. Adeel (2008) considered traditional knowledge a huge asset to improved water management in drylands, due to the practices that lead from this knowledge being socially acceptable and sustainable, while acknowledging that traditional knowledge will benefit from scientific rigour as well as south-south exchange of knowledge and solutions.

4.2. Implications for IPCC categories in sub-Saharan African cities

In formulating the methodology for this study, the IPCC categories of adaptation constraints and opportunities were used to guide the framework of the research. While these categories provided a useful structure to work from, it should be noted that a number of nuances were required in the application of these categories in a sub-Saharan African context. Given the unique developmental contexts of African (and sub-Saharan African) cities, this is not a surprising discovery, yet it provides important learning for applying the IPCC categories at a regional scale. As noted at the outset of this paper, the African context is beset with a unique set of challenges and decision-making constraints, influenced by the colonial legacy that has dictated the structure of infrastructure and services, as well as a reliance on the international donor community for many fundamental infrastructural projects. In addition, social and cultural norms cannot be globally homogenised, leading to the need to tailor internationally-derived frameworks for an African context.

As indicated, and of note in this study was the need for the addition of a category of constraints pertaining to '*ethics and intellectual property'*, which is a concerning constraint we found in the cities. It appears to stem from a lack of trust between government and civil society around ownership of intellectual property. Without the ability to freely share entrepreneurial ideas in order to access the necessary capital for implementation, the entrepreneurial sector is significantly hampered in its progress.

Also of note in this study was the need for the addition of a category pertaining to climate change *windows of opportunity*, as opportunities for adaptation. While climate change is often widely noted as a hindrance to global development, some interviewees felt that climate change actually presented opportunities for innovation that otherwise would not have been present. It is hypothesised that this is not a uniquely African phenomenon and therefore should be considered for inclusion in the global IPCC framework of adaptation opportunities.

4.3. New frontiers for exploration

The climate change adaptation and water management space is permeated with contextually informed values, cultural norms and decision contexts that require unpacking, and this raises inherent problems in generalising across geographic regions. This is particularly critical in the contrast between the perspectives of Global South nations and the so-called W.E.I.R.D. nations (Western, Educated, Industrialized, Rich Democracies) (Henrich et al 2010), the latter often steering climate change adaptation initiatives in nations of the Global South. However, this study highlighted the need to better understand and explore factors underlying decision contexts within Africa (and particularly within African cities); an understanding that is currently sparse in the academic discourse.

Further investigation is warranted to better understand the *'ethics and intellectual property' constraint*, not only because this issue may be pertinent in an African context but also because it may have a significant impact on the implementation of successful entrepreneurial enterprises. If found to be a widespread constraint, impartial and independent funding sources may be required in order to circumvent the trust issues that have arisen between the public and private sector.

Finally, this study has highlighted the need to take into account local decision contexts when allocating donor funding so that funding initiatives do not impose inappropriate structures or run counter to the strategic direction of the region. Critically, local experts and stakeholders

should be included in prioritising objectives for donor funding to ensure maximum success of the funding regime within the contextual constraints and needs of the fund recipients.

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