Supplementary Table 1. Qualitative measure of the increase of social entropy and uncertainty towards the apex of the classical information hierarchy.

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| *The demand for locally relevant climate change wisdom is very rarely satisfied because of intangible, unpredictable socially complex and non-linear parameters that contribute to high social entropy*. Barriers and limitations include the complexity and influence of local politics (Bulkeley and Betsill, 2005; Bulkeley and Kern, 2006; Jones et al., 2015; Ordner, 2017; Pasquini and Shearing, 2014); leaders and leadership (Bateman and Mann, 2016; Burch, 2010; Pasquini and Shearing, 2014; Roberts, 2010; Schreurs, 2008), societal desires and objectives(Adger et al., 2009; Pasquini et al., 2013; Smit and Wandel, 2006; van der Voorn et al., 2017), fairness and climate justice (Castree et al., 2014; Paavola and Adger, 2006; Shi et al., 2016) and the role of networks (Bidwell et al., 2013; Pasquini and Shearing, 2014; Pelling et al., 2008).**Local politics** or the emergence of new political spaces has become complex vertical linkages between state institutions (Bulkeley and Betsill, 2005). Politics itself is inherently contentious and its instability disrupts patterns in champions and networks and clientelism (Ordner, 2017)(Pasquini and Shearing, 2014). Gaining local support and working within the context of ambiguity is political challenge of governing climate change (Bulkeley and Kern, 2006). The immediacy of development challenges inevitably focuses the attention of decision-makers on shorter timescales (Jones et al., 2015).Politics shares a close relationship with the expectations on **leaders and leadership** in general. It is high-level directive leadership that stimulates an organizational culture of innovation and collaboration and make decisions to prioritize climate change action (Burch, 2010)(Schreurs, 2008). Leadership requires a variety of activities including administrating, enabling and adapting to changing environments (Bateman and Mann, 2016). The multi-dimensional complexity of climate change requires leadership that is equally transcendent and bridge lateral boundaries rather than working along hierarchical authority lines (Bateman and Mann, 2016). There is recognition of the need for identifiable political/administrative champion(s) for climate change issues (Pasquini and Shearing, 2014)(Roberts, 2010). **Societal desires and objectives** expressed as broader social, cultural, economic and political forces may also constrained or even nullified adaptive capacity and action (Smit and Wandel, 2006)(Adger et al., 2009). Adaptations are also rarely undertaken in response to climate change effects alone (Smit and Wandel, 2006) but a participatory development of societal vision and objectives is a powerful tool for climate change adaptation planning (van der Voorn et al., 2017). Climate change adaptation can be limited or delayed by social and cultural barriers (Pasquini et al., 2013).The issue of **fairness and climate justice** demands a broadening participation in climate adaptation planning (Paavola and Adger, 2006). This is an important consideration for rapidly growing cities and those with low financial or institutional capacity. Adaptation planning requires adopting a multilevel and multi-scalar approach that also integrates justice into infrastructure and urban design processes (Shi et al., 2016). Climate change science is still considered to have a limited conception of social science and the humanities (Castree et al., 2014).The role of **networks** in facilitating or hindering is an important consideration for adaptation planning. Networks or “shadow systems” are often hidden but have implicit patterns of behaviour and organisation that are hard to delineate and control (Pelling et al., 2008). Such networks exist between the municipality and other organizations, and within the municipality. These networks forge connections among rapidly changing communities of decision-makers and researchers and can foster the social learning necessary for effective adaptation to climate risks (Bidwell et al., 2013)(Pasquini and Shearing, 2014).  |
| *The demand for locally relevant climate change knowledge is very rarely satisfied because of a range of less ethereal but equally debilitating for adaptation planning*. Barriers and limitations include institutional settings (Aylett, 2015; Baker et al., 2012; Beller-Simms et al., 2008; Colenbrander and Bavinck, 2017; Gallopin et al., 2001; Pasquini et al., 2013; Schreurs, 2008), alignment of local policy (Araos et al., 2017; Carter et al., 2015; Larsen et al., 2012; Measham et al., 2011; Posas, 2011; Roberts, 2008; Sok et al., 2011), engagement of society (Baker et al., 2012; Prieur-Richard et al., 2018; Weichselgartner and Kasperson, 2010; Wilson, 2006), and resource limitations and budget cuts (Baker et al., 2012; Nordgren et al., 2016; Porter et al., 2015).**Institutional settings** matter in terms of the potential for local governments to take the initiative(Schreurs, 2008). Often there are institutional limitations relating to procedural rigidity delivered by the bureaucracy (Colenbrander and Bavinck, 2017), multiplicity of legitimate perspectives and irreducible uncertainty (Gallopin et al., 2001), and key structural, procedural, regulatory and contextual limitations (for adaptation)(Baker et al., 2012)(Pasquini et al., 2013). Adaptation often does not fit individual institutional silos (Aylett, 2015). Inflexible decision-making frameworks are likely to limit the use information (Beller-Simms et al., 2008).Linked to the institutional setting is the **alignment of local policy** instruments and the incorporation of climate change considerations into administrative decision making(Roberts, 2008). Spatial Planning in general but spatial planning in particular provides a key policy lever that can be applied to the task of urban adaptation(Carter et al., 2015) and mainstream adaptation actions (Measham et al., 2011). Current municipal plans often focus on identifying vulnerability and impacts rather than adaptation strategies (Araos et al., 2017). Furthermore, climate change related regulation and guidelines for the EIA process remains a challenge (Sok et al., 2011). Equally so, strategic environmental assessment (SEA) process is well-positioned to systematically help strengthen treatment of climate change adaptation and mitigation in planning and development (Larsen et al., 2012; Posas, 2011). The genuinely (authentic) **engagement of society**, and the use of transdisciplinary approaches (Prieur-Richard et al., 2018) when developing climate adaptation plans remains a challenge (Baker et al., 2012). Equally so, is the lack of engagement of the planning profession with climate change networks (Wilson, 2006). Including multiple stakeholders and providing end-users with more, and more transparent, access to the research process early engagement of end-users in defining data needs to create a research process more likely to produce salient knowledge (Weichselgartner and Kasperson, 2010).**Resource limitations and budget cuts** (and a lack of political support) from central government remains an barrier for long-term climate adaptation (Porter et al., 2015). Faced with such limitations better knowledge has not translated into tangible adaptation actions. There is a particular dearth in resources supporting the later phases of the adaptation process (Nordgren et al., 2016). Ongoing funding to maintain engagement with society is also a concern (Baker et al., 2012). |
| *The demand for locally relevant climate change information is often not satisfied because of the insufficient availability of appropriate climate information.* The need for climate change information at the regional-to-local level is one of the central issues within the global change debate and there are many examples of how such information is becoming available (Abba Omar and Abiodun, 2017; Giorgi, 2006; Giorgi et al., 2009). The efforts of the IPCC in this regards is noticeable (IPCC, 2013). However, scientific and technical factors account for only a fraction of the barriers to information uptake (Jones et al., 2015). Barriers and limitations include the nature and type of climate information (Amundsen et al., 2010; Briley et al., 2015; Jones et al., 2015; Lemos et al., 2012; Pasquini et al., 2013; Porter et al., 2015; Ranney and Clark, 2016; Tribbia and Moser, 2008), and resource and capacity limitations (Lemos et al., 2012; Pasquini et al., 2013).There remains opportunities and limitations linked to the **nature and type of climate information** for adaptation. Climate information products is more likely to be deployed if they perceive to be accurate, credible, salient and timely (Amundsen et al., 2010; Lemos et al., 2012). Information delivered to decision-makers is often overly technical and prone to misunderstanding of associated uncertainties and suitability to their needs (Jones et al., 2015). Managers also prefer certain types of information and information sources to make better use of global change information (Tribbia and Moser, 2008)(Porter et al., 2015). Matching terminology between scientists and stakeholders, unrealistic expectations from and disordered integration of climate information remains a problem for decision-making processes (Briley et al., 2015). However, extant climatological evidence/theory, e.g. IPCC Assessment Reports, is driving increasing acceptance of global warming and anthropogenicity (Ranney and Clark, 2016). Even so, municipalities still lack access to credible, practical and relevant information on climate change impacts (Pasquini et al., 2013).Even though climate change information is becoming increasingly common, **resource and capacity limitations** at the local government level remains a challenge. Sufficient human or technical capacity in-house or access to external relevant expertise makes climate forecast use more likely (Lemos et al., 2012) while there are still cognitive and individual barriers to climate change adaptation (Pasquini et al., 2013). |
| *Notwithstanding the volume of global and regional climate data available, the demand for locally relevant climate change data is only sometimes satisfied* since specific adaptation measures requires information on specific parameters not yet evaluated in climate model simulations (Hackenbruch et al., 2017). Barriers and limitations includes the lack of access to technical data (Jones et al., 2015; Measham et al., 2011; Prieur-Richard et al., 2018), and the scale and type of data (Bai et al., 2018; Cheng et al., 2017; Lorenz et al., 2017; Moss et al., 2010; Prieur-Richard et al., 2018).The **lack of access to technical data**, unfamiliarity with such data, and a lack of expertise still affect local adaptation (Measham et al., 2011). Similarly, there is a need for international and open-access observational framework for collecting key climate and socio-economic metrics at the city level (Jones et al., 2015; Prieur-Richard et al., 2018). The **scale and type of data** is also important and climate simulations need to account for urbanization, and be scaled down to city and neighbourhood levels (Bai et al., 2018). Improving modelling capabilities remains key to producing higher resolution data, predicting near term climate futures, and producing models that are customisable to specific cities (Prieur-Richard et al., 2018). Downscaling of climate change scenarios is in this context both, a critical issue with regards to availability of data and costs. This lack of down-scaled climate change data and place-based assessment has discouraged local communities to pursue further climate change plans (Cheng et al., 2017). Even so, there is still little demand for climate projections in local adaptation planning (Lorenz et al., 2017). Decadal scale predictions and how it is communicated to society remains a challenge (Moss et al., 2010) |

**References**

Abba Omar, S., Abiodun, B.J., 2017. How well do CORDEX models simulate extreme rainfall events over the East Coast of South Africa? Theor. Appl. Climatol. 128, 453–464. https://doi.org/10.1007/s00704-015-1714-5

Adger, W.N., Dessai, S., Goulden, M., Hulme, M., Lorenzoni, I., Nelson, D.R., Naess, L.O., Wolf, J., Wreford, A., 2009. Are there social limits to adaptation to climate change? Clim. Change 93, 335–354. https://doi.org/10.1007/s10584-008-9520-z

Amundsen, H., Berglund, F., Westskog, H., 2010. Overcoming barriers to climate change adaptation—a question of multilevel governance? Environ. Plan. C Gov. Policy 28, 276–289. https://doi.org/10.1068/c0941

Araos, M., Ford, J., Berrang-Ford, L., Biesbroek, R., Moser, S., 2017. Climate change adaptation planning for Global South megacities: the case of Dhaka. J. Environ. Policy Plan. 19, 682–696. https://doi.org/10.1080/1523908X.2016.1264873

Aylett, A., 2015. Institutionalizing the urban governance of climate change adaptation: Results of an international survey. Urban Clim. 14, 4–16. https://doi.org/10.1016/j.uclim.2015.06.005

Bai, X., Dawson, R.J., Ürge-Vorsatz, D., Delgado, G.C., Salisu Barau, A., Dhakal, S., Dodman, D., Leonardsen, L., Masson-Delmotte, V., Roberts, D.C., Schultz, S., 2018. Six research priorities for cities and climate change. Nature 555, 23–25. https://doi.org/10.1038/d41586-018-02409-z

Baker, I., Peterson, A., Brown, G., McAlpine, C., 2012. Local government response to the impacts of climate change: An evaluation of local climate adaptation plans. Landsc. Urban Plan. 107, 127–136. https://doi.org/10.1016/j.landurbplan.2012.05.009

Bateman, T.S., Mann, M.E., 2016. The supply of climate leaders must grow. Nat. Clim. Chang. 6, 1052–1054. https://doi.org/10.1038/nclimate3166

Beller-Simms, N., Ingram, H., Feldman, D., Mantua, N., Jacobs, K.L., Waple, A., 2008. Decision-Support Experiments and Evaluations using Seasonal-to-Interannual Forecasts and Observational Data:A Focus on Water Resources, Synthesis and Assessment Product 5.3 Report.

Bidwell, D., Dietz, T., Scavia, D., 2013. Fostering knowledge networks for climate adaptation. Nat. Clim. Chang. 3, 610–611. https://doi.org/10.1038/nclimate1931

Briley, L., Brown, D., Kalafatis, S.E., 2015. Overcoming barriers during the co-production of climate information for decision-making. Clim. Risk Manag. 9, 41–49. https://doi.org/10.1016/j.crm.2015.04.004

Bulkeley, H., Betsill, M.M., 2005. Rethinking sustainable cities: Multilevel governance and the “urban” politics of climate change. Env. Polit. 14, 42–63. https://doi.org/10.1080/0964401042000310178

Bulkeley, H., Kern, K., 2006. Local government and the governing of climate change in Germany and the UK. Urban Stud. 43, 2237–2259. https://doi.org/10.1080/00420980600936491

Burch, S., 2010. Transforming barriers into enablers of action on climate change: Insights from three municipal case studies in British Columbia, Canada. Glob. Environ. Chang. 20, 287–297. https://doi.org/10.1016/j.gloenvcha.2009.11.009

Carter, J.G., Cavan, G., Connelly, A., Guy, S., Handley, J., Kazmierczak, A., 2015. Climate change and the city: Building capacity for urban adaptation. Prog. Plann. 95, 1–66. https://doi.org/10.1016/j.progress.2013.08.001

Castree, N., Adams, W.M., Barry, J., Brockington, D., Büscher, B., Corbera, E., Demeritt, D., Duffy, R., Felt, U., Neves, K., Newell, P., Pellizzoni, L., Rigby, K., Robbins, P., Robin, L., Rose, D.B., Ross, A., Schlosberg, D., Sörlin, S., West, P., Whitehead, M., Wynne, B., 2014. Changing the intellectual climate. Nat. Clim. Chang. 4, 763–768. https://doi.org/10.1038/nclimate2339

Cheng, C., Yang, Y.C.E., Ryan, R., Yu, Q., Brabec, E., 2017. Assessing climate change-induced flooding mitigation for adaptation in Boston’s Charles River watershed, USA. Landsc. Urban Plan. 167, 25–36. https://doi.org/10.1016/j.landurbplan.2017.05.019

Colenbrander, D., Bavinck, M., 2017. Exploring the role of bureaucracy in the production of coastal risks, City of Cape Town, South Africa. Ocean Coast. Manag. 150, 35–50. https://doi.org/10.1016/j.ocecoaman.2016.11.012

Gallopin, G.C., Funtowicz, S., O’Connor, M., Ravetz, J., 2001. Science for the Twenty-First Century: From Social Contract to the Scientific Core. Int. Soc. Sci. J. 53, 219–229. https://doi.org/10.1111/1468-2451.00311

Giorgi, F., 2006. Regional climate modeling: Status and perspectives. J. Phys. IV 139, 101–118. https://doi.org/10.1051/jp4:2006139008

Giorgi, F., Jones, C., Asrar, G.R., 2009. Addressing climate information needs at the regional level: The CORDEX framework. World Meteorol. Organ. Bull. 58, 175–183.

Hackenbruch, J., Kunz-Plapp, T., Müller, S., Schipper, J., 2017. Tailoring Climate Parameters to Information Needs for Local Adaptation to Climate Change. Climate 5, 25. https://doi.org/10.3390/cli5020025

IPCC, 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovern- mental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA.

Jones, L., Dougill, A., Jones, R.G., Steynor, A., Watkiss, P., Kane, C., Koelle, B., Moufouma-Okia, W., Padgham, J., Ranger, N., Roux, J.P., Suarez, P., Tanner, T., Vincent, K., 2015. Ensuring climate information guides long-term development. Nat. Clim. Chang. 5, 812–814. https://doi.org/10.1038/nclimate2701

Larsen, S.V., Kørnøv, L., Wejs, A., 2012. Mind the gap in SEA: An institutional perspective on why assessment of synergies amongst climate change mitigation, adaptation and other policy areas are missing. Environ. Impact Assess. Rev. 33, 32–40. https://doi.org/10.1016/j.eiar.2011.09.003

Lemos, M.C., Kirchhoff, C.J., Ramprasad, V., 2012. Narrowing the climate information usability gap. Nat. Clim. Chang. 2, 789–794. https://doi.org/10.1038/nclimate1614

Lorenz, S., Dessai, S., Forster, P.M., Paavola, J., 2017. Adaptation planning and the use of climate change projections in local government in England and Germany. Reg. Environ. Chang. 17, 425–435. https://doi.org/10.1007/s10113-016-1030-3

Measham, T.G., Preston, B.L., Brooke, C., Smith, T.F., Morrison, C., Withycombe, G., Gorddard, R., Brooke, C., Gorddard, R., Withycombe, G., Morrison, C., 2011. Adapting to climate change through local municipal planning: barriers and challenges. Mitig. Adapt. Strateg. Glob. Chang. 16, 889–909. https://doi.org/10.1007/s11027-011-9301-2

Moss, R.H., Edmonds, J.A., Hibbard, K.A., Manning, M.R., Rose, S.K., van Vuuren, D.P., Carter, T.R., Emori, S., Kainuma, M., Kram, T., Meehl, G.A., Mitchell, J.F.B., Nakicenovic, N., Riahi, K., Smith, S.J., Stouffer, R.J., Thomson, A.M., Weyant, J.P., Wilbanks, T.J., 2010. The next generation of scenarios for climate change research and assessment. Nature 463, 747–756. https://doi.org/10.1038/nature08823

Nordgren, J., Stults, M., Meerow, S., 2016. Supporting local climate change adaptation: Where we are and where we need to go. Environ. Sci. Policy 66, 344–352. https://doi.org/10.1016/j.envsci.2016.05.006

Ordner, J.P., 2017. Community action and climate change. Nat. Clim. Chang. 7, 161–163. https://doi.org/10.1038/nclimate3236

Paavola, J., Adger, W.N., 2006. Fair adaptation to climate change. Ecol. Econ. 56, 594–609. https://doi.org/10.1016/j.ecolecon.2005.03.015

Pasquini, L., Cowling, R.M., Ziervogel, G., 2013. Facing the heat: Barriers to mainstreaming climate change adaptation in local government in the Western Cape Province, South Africa. Habitat Int. 40, 225–232. https://doi.org/10.1016/j.habitatint.2013.05.003

Pasquini, L., Shearing, C., 2014. Municipalities, Politics, and Climate Change: An Example of the Process of Institutionalizing an Environmental Agenda Within Local Government. J. Environ. Dev. 23, 271–296. https://doi.org/10.1177/1070496514525406

Pelling, M., High, C., Dearing, J., Smith, D., 2008. Shadow spaces for social learning: A relational understanding of adaptive capacity to climate change within organisations. Environ. Plan. A 40, 867–884. https://doi.org/10.1068/a39148

Porter, J.J., Demeritt, D., Dessai, S., 2015. The right stuff? Informing adaptation to climate change in British Local Government. Glob. Environ. Chang. 35, 411–422. https://doi.org/10.1016/j.gloenvcha.2015.10.004

Posas, P.J., 2011. Exploring climate change criteria for strategic environmental assessments. Prog. Plann. 75, 109–154. https://doi.org/10.1016/j.progress.2011.05.001

Prieur-Richard, A.-H., Walsh, B., Craig, M., Melamed, M., Colbert, M.L., Pathak, M., Connors, S., Bai, X., Barau, A., Bulkeley, H., Cleugh, H., Colenbrander, S., Dodman, D., Dhakal, S., Dawson, R., Greenwalt, J., Kurian, P., Lee, B., Leonardson, L., Masson-delmotte, V., Munshi, D., Okem, A., Ramos, G.C.D., Rodriguez, R.S., Roberts, D., Rosenzweig, C., Schultz, S., Seto, K., Solecki, W., Van, M., Ürge-vorsatz, D., 2018. Global Research and Action Agenda on Cities and Climate Change Science. Incheon, Korea.

Ranney, M.A., Clark, D., 2016. Climate Change Conceptual Change: Scientific Information Can Transform Attitudes. Top. Cogn. Sci. 8, 49–75. https://doi.org/10.1111/tops.12187

Roberts, D., 2010. Prioritizing climate change adaptation and local level resilience in Durban, South Africa. Environ. Urban. 22, 397–413. https://doi.org/10.1177/0956247810379948

Roberts, D., 2008. Thinking globally, acting locally: institutionalizing climate change at the local government level in Durban, South Africa. Environ. Urban. 20, 521–537. https://doi.org/10.1177/0956247808096126

Schreurs, M., 2008. From the bottom up: Local and substantial climate change politics. J. Environ. Dev. 17, 343–355.

Shi, L., Chu, E., Anguelovski, I., Aylett, A., Debats, J., Goh, K., Schenk, T., Seto, K.C., Dodman, D., Roberts, D., Roberts, J.T., Van Deveer, S.D., 2016. Roadmap towards justice in urban climate adaptation research. Nat. Clim. Chang. 6, 131–137. https://doi.org/10.1038/nclimate2841

Smit, B., Wandel, J., 2006. Adaptation, adaptive capacity and vulnerability. Glob. Environ. Chang. 16, 282–292. https://doi.org/10.1016/j.gloenvcha.2006.03.008

Sok, V., Boruff, B.J., Morrison-Saunders, A., 2011. Addressing climate change through environmental impact assessment: International perspectives from a survey of IAIA members. Impact Assess. Proj. Apprais. 29, 317–326. https://doi.org/10.3152/146155111X12959673796001

Tribbia, J., Moser, S.C., 2008. More than information: what coastal managers need to plan for climate change. Environ. Sci. Policy 11, 315–328. https://doi.org/10.1016/j.envsci.2008.01.003

van der Voorn, T., Quist, J., Pahl-Wostl, C., Haasnoot, M., 2017. Envisioning robust climate change adaptation futures for coastal regions: a comparative evaluation of cases in three continents. Mitig. Adapt. Strateg. Glob. Chang. 22, 519–546. https://doi.org/10.1007/s11027-015-9686-4

Weichselgartner, J., Kasperson, R., 2010. Barriers in the science-policy-practice interface: Toward a knowledge-action-system in global environmental change research. Glob. Environ. Chang. 20, 266–277. https://doi.org/10.1016/j.gloenvcha.2009.11.006

Wilson, E., 2006. Adapting to Climate Change at the Local Level: The Spatial Planning Response. Local Environ. 11, 609–625. https://doi.org/10.1080/13549830600853635