are evaluating strategies to reduce risk in light of climate change by setting risk thresholds, agreeing on models and communicating the need to reduce risks. Jakarta is currently devising a multibillion dollar programme to protect itself from rising sea levels with large levees. Jakarta also recognizes the short-term effects of rapid urbanization, and is studying options to implement new building and zoning regulations to lower the exposure and vulnerability of houses and infrastructure to extreme rainfall[17]. New York City is rebuilding areas affected by Hurricane Sandy using a layered risk management approach. New building codes are being developed as part of a longer-term vision to adapt to climate change, while revisiting the current flood insurance arrangements and associated incentives to reduce risk[18].

Processes can quickly become normative and subject to political debate due to varying interpretations of the underlying risk science. A hurricane risk model recently developed to support insurance decisions in Florida was not licensed by the insurance regulator as modellers proposed to break with the tradition of averaging hurricane losses over the long term by giving more weight to higher hurricane activity in recent years (as possibly induced by climatic change)[19]. Furthermore, risk thresholds are often defined following political negotiations rather than concepts of risk efficiency and ability to absorb risk. For example, the 75-year return period threshold, the lowest return period for which flood insurance in the UK is available, was chosen as a compromise — the middle ground between industry and government willingness to bear risk (based on unpublished interviews conducted by Surminski in 2009).

Moving forward

If the risk-layering approach is to be useful for moving the loss and damage agenda beyond the red lines, it will require extensive effort in collecting relevant data for modelling risks in a changing climate, identifying efficient risk-reduction activities and supporting safety nets for the most vulnerable. Still, there will be hurdles, not least in terms of involving stakeholders in assessing risks and proposing effective and fair management policies. An iterative and participatory risk-management process, informed by the best possible risk science for studying the key drivers — hazards, exposure and vulnerability — will be needed. This agenda can benefit greatly from an understanding of the differentiated activities targeted at different risk layers. Identifying opportunities and limits to risk reduction, risk transfer and adaptation, as well as supporting the victims through international efforts, must be core to the evolving loss and damage mechanism. ❐

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References

1. UNFCCC *Decision CP.19* (UNFCCC, 2013).
2. IPCC *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (eds Field, C. B. *et al.*) (Cambridge Univ. Press, 2012).
3. Stern, P. *et al. Nature Clim. Change* **3,** 607–609 (2013).
4. Huggel, C. *et al. Nature Clim. Change* **3,** 694–696 (2013).
5. Swart, R. *et al. Nature Clim. Change* **3,** 942–943 (2013).
6. Verheyen, R. *Tackling Loss & Damage –A New Role for the Climate Regime?* (Climate and Development Knowledge Network, 2012).
7. IPCC *Climate Change 2013: The Physical Science Basis* (eds Stocker, T. *et al.*) (Cambridge Univ. Press, 2013).
8. Bouwer, L. M. *Bull. Am. Meteorol. Soc.* **92,** 39–46 (2011).
9. Stone, J. *J. Risk Insur.* **40,** 231–243 (1973).
10. Linnerooth-Bayer, J. & Hochrainer-Stigler, S. *Climatic Change* http://doi.org/rn7 (2014).
11. Dow. K. *et al. Nature Clim. Change* **3,** 305–307 (2013).
12. *Foresight: Reducing Risks of Future Disasters* (UK Government Office of Science, 2012).
13. *Report on the Fifth Quantitative Impact Study (QIS5) for Solvency II* (European Insurance and Occupational Pensions Authority, 2011).
14. Mechler, R. *et al. Assessing the Financial Vulnerability to Climate-Related Natural Hazards — World Bank Policy Research Working Paper 5232* (World Bank, 2010).
15. Kellett, J. & Caravani, A. *Financing Disaster Risk Reduction* (GFDRR and ODI, 2013).
16. Linnerooth-Bayer, J. *et al. The Geneva Papers* **34,** 381–400 (2009).
17. Ward, P. J. *et al. Nat. Hazards* **56,** 899–916 (2011).
18. Aerts, J. C. J. H. & Botzen, W. J. *Nature Clim. Change* **2,** 377 (2012).
19. Phelan, L, Henderson-Sellers, A. & Taplin, R. in *The Economic, Social and Political Elements of Climate Change* (ed. Filho, W. L.) 81–98 (Springer, 2011).
20. Hochrainer, S., Mechler, R., Pflug, G. & Williges, K. *Glob. Environ. Change* (in the press).

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COMMENTARY:

Low-carbon investment risks and de-risking

Tobias S. Schmidt

Effective mitigation of climate change requires investment flows to be redirected from high- to low-carbon technologies. However, especially in developing countries, low-carbon investments often suffer from high risks. More research is needed to address these risks and allow sound policy decisions to be made.

Climate policy has to address a global investment challenge. The International Energy Agency estimates that in the energy sector alone, infrastructure investments of US$37 trillion will be needed by 2035[1] to meet the rising global energy demand. To achieve an atmospheric CO_2 concentration below 450 parts per million, these investment flows have to be redirected from high-carbon to low-carbon technologies and topped up by a further US$17 trillion[1]. This can realistically be achieved only by successfully mobilizing private capital[2]. Consequently, climate policy needs to create attractive conditions for private low-carbon investments, especially in countries not belonging to the Organisation for Economic Co-operation and Development where the

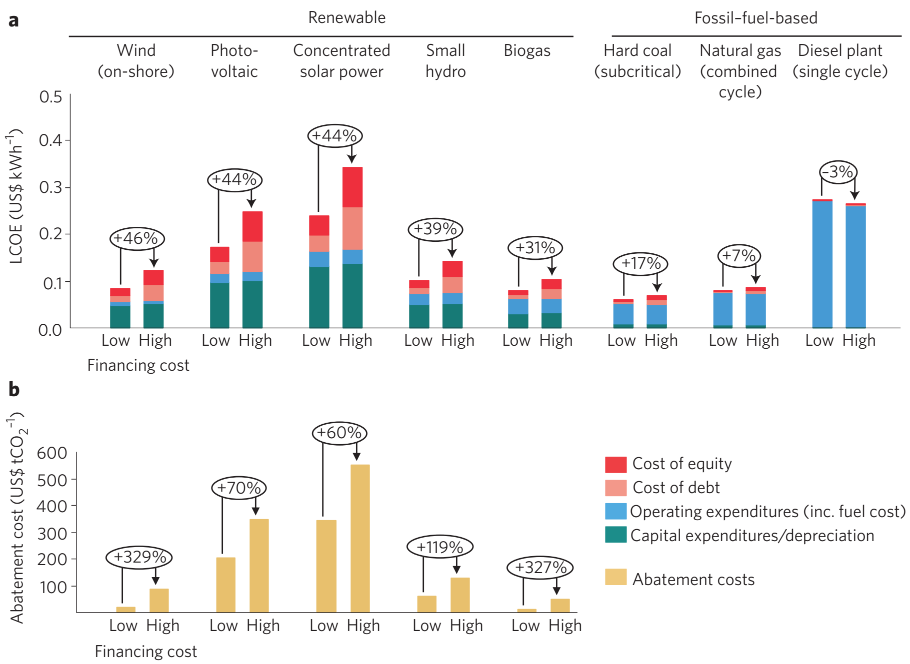

Figure 1 | The impact of risk on the cost of power generation. The left bar for each technology assumes a low cost of capital: 5% cost of debt, 10% cost of equity (typical current values in an industrialized country), whereas the right bar assumes a high cost of capital: 10% cost of debt, 18% cost of equity (typical current values for a low-income country[11]). Although this figure assumes differences in only the capital costs, higher risks typically also affect other financial parameters, such as the capital structure (that is, the relationship between equity and capital) or the loan tenor (that is, the maturity of the bank loan). Changes in these parameters further increase the role of risk[11]. **a**, The pre-tax levelized cost of electricity (LCOE) in US dollars per kilowatt hour. The different stacks depict the different cost components (see legend). The fact that the LCOE diesel decreases with higher capital costs is related to discounting effects on fuel costs. **b**, The cost of emission abatement in US dollars per ton of CO_2. A marginal baseline consisting of 50% hard coal and 50% natural gas is assumed. All costs given in US dollars at 2012 value.

lion's share of investments are needed[1]. As the private sector makes investment decisions based on the risk–return profile of investment opportunities[3], there are two levers for climate policy: first, increase the returns of low-carbon investments (or decrease those of high-carbon investments); second, decrease the downside risk of low-carbon investments, also called de-risking.

Although existing literature shows the importance of risk in determining private investments[3] — especially in developing countries where investment risks are typically higher than in developed countries[4,5] — hitherto most climate policy instruments, such as the Kyoto Protocol's Clean Development Mechanism, have focused on the return lever. In contrast, future climate policy might incorporate both levers through Nationally Appropriate Mitigation Actions[6] and activities of the Green Climate Fund[7]. However, debate remains about how the underlying public instruments should be designed and to what extent resources should be devoted to one or the other lever[6,8]. Further research on low-carbon investment risks and de-risking is needed. Here, I focus on the role of risk in low-carbon investments, explain the concept of de-risking and propose five steps for future research.

Risk in low-carbon investments

Downside risk is the combination of the likelihood of the occurrence of a negative event and its associated financial impact[9]. Examples of the many potential negative events that may affect fixed asset investments and thereby drive risks include construction delays owing to complicated permitting processes, loss of assets owing to expropriation or default in payment by the customer. The decisions of investors are influenced by the likelihood and impact of such events. The perception of risk is then reflected in the financing costs or cost of capital[3]: with higher investment risks, a bank raises the interest rate (cost of debt) and an equity investor raises the return expectation (cost of equity). This is true for both high- and low-carbon investments. However, low-carbon technologies are much more capital-intensive than their high-carbon alternatives, whose costs are mainly dictated by the cost of fuels. Therefore, investment risks and the related financing costs are more significant for low-carbon projects. Figure 1a depicts the typical power generation cost of five renewable and three fossil-fuel-based technologies. For each technology, the left bar shows the life-cycle cost assuming low financing costs (in an industrialized country), whereas the right bar assumes higher financing costs (typical in developing countries). A clear pattern emerges: the life-cycle costs of capital-intensive renewable energy technologies are much more sensitive to the increase in financing costs (+31% to +46%) than those of technologies dominated by fuel cost (−3% to +17%), as shown in Fig. 1a. Higher investment risks thereby decrease the competitiveness of renewables *vis à vis* fossil-fuel-based technologies. This is also reflected in the marginal abatement costs depicted in Fig. 1b, which strongly increase with higher risks. In particular, competitive low-carbon technologies whose abatement costs are low (for example, wind, small hydro and biogas), are strongly affected by higher risks when compared with a fossil fuel baseline (experiencing abatement cost increases of up to 330%).

Addressing investment risks

Given the importance of investment risks, de-risking is a potentially powerful policy option to redirect financial flows from high- to low-carbon investments. De-risking lowers the financing costs and consequently the greenhouse gas abatement costs of low-carbon technologies. It works in two ways — financial and policy de-risking. As for the first, the financial impact of a negative event is reduced by transferring large portions of the impact to other parties. Examples are risk insurance or guarantees offered by public sector actors (such as development banks) who cover damages, for example, in the form of reduced or no payment by the customer. As for the second, the likelihood of a negative event is reduced by removing barriers in the investment environment and improving local institutions. An example is a streamlined permitting process that reduces the likelihood of construction delays.

A report published in 2011 by Deutsche Bank provides the conceptual basis for the idea of low-carbon de-risking and its economic effects[10]. In April 2013, the United Nations Development Programme published *Derisking Renewable Energy Investment* (ref. 11) — a report that further develops the concepts of measuring the effects of de-risking in quantitative terms and applies them to onshore wind power in four selected developing countries. The results indicate that de-risking can increase the effectiveness and efficiency of policies aiming to attract low-carbon investments. However, these reports can be seen as only first steps.

Towards a research agenda

Despite the importance of risk and associated financing costs as well as the potential of de-risking, related research and data are scarce. To address this gap, I propose five specific topics essential to improving our knowledge of risk and de-risking.

A global database on financing costs. Despite large differences in risk profiles, at present most energy models and reports assume the same financing costs across countries (for example, 10%; ref. 12). One important reason is the lack of good country-level data. The United Nations Framework Convention on Climate Change has released financing cost estimates for many developing countries[13]; however, their numbers are aggregated at the sector level, only cover the costs of equity and do not match with the observations of other sources. To better inform energy analysts and policymakers, a global database that collects financing costs and other important investment parameters (such as capital structures and loan maturities) is needed. As the data are often sensitive, an international institution should be in place to aggregate and anonymize the data. The International Renewable Energy Agency's renewable cost database[12] has started to collect such data but is limited to renewable energy projects.

Drivers of financing costs. The probabilities of negative events and the financial impacts of such events determine the risks, the financing costs and the investment decisions, and therefore should be documented.

However, in developing countries and especially for infrastructure investments, such information is scarce. Recent studies analysed the relative importance of different risks in selected countries[14,15], but there has been almost no analysis on how these factors translate into higher financing costs. The *Derisking Renewable Energy Investment* report has proposed a linear survey-based method. Although this is a first step in the right direction, experts should develop more sophisticated methodologies that, for example, better incorporate the correlation among risk drivers. To this end, collecting global data on risk drivers is highly relevant and would complement the database proposed above.

Effectiveness of de-risking. It is fairly simple to track the effectiveness of financial de-risking measures in terms of lowering financing costs. As soon as these measures are implemented, the cost of capital is reduced (for example, a bank reduces the interest rate if a World Bank loan guarantee is provided). For policy de-risking measures this is not the case: their effects build up only over time, as investors gain trust. This makes the evaluation of effectiveness more complex. At present there are no studies analysing these effects over time, which calls for future research.

Efficiency of de-risking. To evaluate the efficiency of de-risking measures, one needs to compare their financial effects with their costs. Financial de-risking measures are effective immediately (see above) and produce costs for each new project, making their efficiency evaluation quite easy. In contrast, policy de-risking measures are often long-term in nature (for example, building up a new streamlined permitting process). They produce most costs before the projects take place but only small (or no) extra costs with each project that follows. Therefore, they hold the potential to reduce the long-term dependence of developing countries on international assistance. Although the literature on development issues provides methods to track the efficiency of assistance measures, at present these measures do not refer to financing costs and studies fail to relate this efficiency to climate change mitigation.

Political feasibility of de-risking. Once new methods and data are available, future research will need to develop workable policy recommendations for national and international institutions. At a national level, research on the design of low-emission development strategies and nationally appropriate mitigation actions that make use of the de-risking lever is needed. At an international level, recommendations should be developed on how the Green Climate Fund can assure its funds are efficiently distributed between the return and the risk lever (and between financial and policy de-risking). Also, experts should discuss how de-risking can be embedded in a global post-Kyoto policy regime. To this end, standards are needed that allow measuring, reporting and verifying the effectiveness and efficiency of climate policies and climate finance in a comparable way.

De-risking can be a powerful lever to address the investment challenge underlying climate change mitigation. Therefore I strongly encourage researchers from many disciplines to help improve our understanding of risk and de-risking and thereby allow the full potential of this lever to be tapped. ❒

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References

1. IEA *World Energy Outlook 2012* (International Energy Agency, 2012).
2. Buchner, B., Falconer, A., Hervé-Mignucci, M. & Trabacchi, C. *The Landscape of Climate Finance 2012* (Climate Policy Initiative, 2012).
3. Brealey, R. A. & Myers, S. C. *Principles of Corporate Finance* 6th edn (McGraw-Hill, 2000).
4. MIGA *World Investment and Political Risk 2012* (World Bank Group, 2012).
5. Schneider, F. & Frey, B. S. *World Dev.* **13,** 161–175 (1985).
6. Hoehne, N. *Nature Clim. Change* **1,** 31–33 (2011).
7. Farrukh, I. K. & Dustin, S. S. *Nature Clim. Change* **3,** 692–694 (2013).
8. Chatham House *Private Sector Consultation to Support the Work of the Transitional Committee for the Design of the Green Climate Fund* (Chatham House, 2011).
9. International Standardisation Organisation *ISO Guide 73, Risk Management - Vocabulary* (International Standardization Organization, 2009).
10. Deutsche Bank Climate Change Advisors *Get FiT Plus - De-Risking Clean Energy Business Models in a Developing Country Context* (DB Climate Change Advisors, 2011).
11. Waissbein, O., Glemarec, Y., Bayraktar, H. & Schmidt, T. S. *Derisking Renewable Energy Investment* (United Nations Development Programme, 2013).
12. IRENA *Renewable Power Generation Costs in 2012: An Overview* (International Renewable Energy Agency, 2013).
13. UNFCCC *Draft Revision to the Guidelines on the Assessment of Investment Analysis* (United Nations Framework Convention on Climate Change, 2010).
14. Komendantova, N., Patt, A., Barras, L. & Battaglini, A. *Energ. Policy* **40,** 103–109 (2012).
15. Shrimali, G., Nelson, D., Goel, S., Konda, C. & Kumar, R. *Energ. Policy* **62,** 28–43 (2013).

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