to be collected (such as deaths, injuries, economic loss, people affected). Protocols (or ontologies) for hazard and impact definitions also are needed to ensure compatible loss attribution, particularly for complex events consisting of multiple hazard types.

Furthermore, to foster trust, transparency and accountability, the information must be publicly available and curated by accepted bodies, which may (or may not) be meteorological agencies, statistical bureaus, or universities. Focusing on the impacts of the last major tropical cyclone or winter storm should not overshadow the chronic impacts from prolonged droughts or routine flooding. The livelihoods of people are not only affected by catastrophic events, but the everyday hazards that adversely affect their resilience.

Help is on the way

International research and infrastructure initiatives such as the Integrated Research on Disaster Risk (IRDR) can support this process of developing protocols for managing loss databases, which greatly increases transparency and data compatibility. There are numerous examples of these science-based inputs. For example, the Joint Research Centre of the European Commission is developing frameworks for loss in European nations[7]. Science-based expert guidance on peril harmonization and hazard terminology is available[13] and is being implemented in many of the existing global (NatCatSERVICE, sigma, EM-DAT) and national (DesInventar, SHELDUS) loss databases. Similarly, a framework for defining and measuring human and economic disaster loss indicators was recently produced[14].

There is no need to establish new and separate bureaucratic structures for disaster loss accounting. Instead, it should be part of existing statistical accounting efforts within countries, whether in the development agencies, environmental departments, or censuses. Such accounting also means the impacts of climate-induced events such as sea-level rise, coastal erosion and flooding, and saltwater intrusion should be included. Establishing separate databases on climate change impacts will only further the fragmentation of loss accounting without resolving issues of data quality, terminology, data coverage and loss quantification.

What does this mean for the Sendai targets? We have well-established indicators for measuring development such as poverty, literacy, or gross domestic product. Why not the same for disaster and extreme event losses? One could argue that disasters impede development, so disaster risk reduction should become the foundation for sustainable development as well as a pillar of climate change adaptation. Without knowing the true impact of small- to large-scale events, planners, government officials and stakeholders are not held accountable for placing people and infrastructure into harm's way along coastlines or on floodplains. Waiting for the human and socioeconomic loss escalator to go up rather than trying to reverse its course has become a global pastime. It's now time to take loss reduction seriously, beginning with national loss inventories as the foundation for risk reduction and for meeting the challenges of the Sendai targets. ❐

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COMMENTARY:

Development incentives for fossil fuel subsidy reform

Michael Jakob, Claudine Chen, Sabine Fuss, Annika Marxen and Ottmar Edenhofer

Reforming fossil fuel subsidies could free up enough funds to finance universal access to water, sanitation, and electricity in many countries, as well as helping to cut global greenhouse-gas emissions.

Fossil fuel subsidies are not only economically inefficient, but also harmful for the environment[1–3]. In 2011, fossil fuel consumption was subsidized by about US$550 billion per year, globally[4] — oil subsidies alone account for economic inefficiencies (that is, annual deadweight losses) of about US$44 billion (ref. 5). Reducing fossil fuel subsidies would also help to protect the climate[6]. Estimates by the International Energy Agency[7] indicate that a universal phase-out of fossil fuel subsidies would lower annual global CO_2 emissions by 4.4%. From this perspective, reducing

Table 1 | Share of population lacking access to basic services by region.

Region	Percentage with no access to electricity	Percentage with no access to water	Percentage with no access to sanitation	Percentage with no access to telecommunications	Percentage of roads that are unpaved
East Asia and Pacific	4.8	8.8	30.6	29.3	40.1
Europe and Central Asia	0.0	2.0	6.5	14.2	23.1
Latin America and the Caribbean	5.2	6.2	18.4	23.0	81.8
Middle East and North Africa	5.3	9.2	11.1	13.8	21.9
North America	0.0	0.8	0.1	1.1	0.0
South Asia	25.6	10.6	61.8	67.9	46.9
Sub-Saharan Africa	68.1	36.7	69.6	59.8	79.6
Global	**16.8**	**11.3**	**36.0**	**37.4**	**31.6**

Regional groupings are according to World Bank classifications[19]. All data are for 2010, from refs 19–21.

or even removing such subsidies seems to be a no-regret option[8]. However, substantial fossil fuel subsidies are granted in many countries, mostly targeted at oil and petroleum products or electricity consumption.

A common explanation for the prevalence of these subsidies lies in political economy motives[9]. Even though low-income groups derive comparatively low benefits from fossil fuel subsidies[10], there is nevertheless considerable opposition to subsidy removal[11], as the resulting rise in energy prices may worsen the situation of the poorest part of the population[12]. For this reason, several policies to make subsidy reform 'pro-poor' have been proposed. These include direct cash transfers (Iran and Georgia) and strengthening social safety nets (Indonesia, Jordan and Moldova) to compensate affected parties for their increased spending on energy[13,14].

Here, we examine what human development benefits could be achieved if these subsidies were redirected to spending on public infrastructure. We put into perspective the amount of fossil fuel subsidies currently deployed in relation to the financial means required to provide access to basic services — in particular, water, sanitation, electricity, telecommunication and paved roads. For these services, access gaps are most severe in Africa and South Asia, but also for some low-income countries in Latin America (see Table 1). For instance, more than two-thirds of the population lacks access to sanitation and electricity in sub-Saharan Africa. Linking fossil fuel subsidy reform to infrastructure investments could not only promote environmental integrity, but also human development. In this way, it could successfully address one of the main obstacles to subsidy reform, namely the concern of adverse development outcomes.

We examine a scenario in which infrastructure investments are undertaken over a period of 15 years, corresponding to the 2015–2030 timeframe of the process to extend the Millennium Development Goals. We assume that without intervention, the share of the population lacking access to a certain infrastructure in the year 2030 would be the same as in the year 2010 (hence our estimates can be considered conservative, as with economic growth it can be expected that access gaps start to shrink as part of the economy's development process and thus a lower share of fossil fuel subsides than the one indicated in our analysis would be needed to achieve universal access). The access gap for each country is then projected by multiplying this share by the population forecast for 2030 (see the Supplementary Information for details).

Our cost calculations indicate that universal access to water for all people on the planet could be achieved by investing US$190 billion, US$370 billion could cover universal access to sanitation, and US$430 billion could finance access to electricity. If spread over a period of 15 years, these amounts are only a small fraction of the US$8.2 trillion in fossil fuel subsidies that would be allotted globally over this period, assuming the allocation remains at 2011 levels. However, more ambitious projects, such as providing universal access to telecommunication (requiring US$2.6 trillion) or paving all unpaved roads (US$8.7 trillion) could take up a large share of (or even exceed) the amount of finance that can be levied by fossil fuel subsidy reform.

Figure 1 displays the share of fossil fuel subsidies that would need to be invested in a particular infrastructure over the period 2015–2030 to achieve universal access at the country level. A lighter colour indicates that a lower share of current subsidies would be sufficient to meet infrastructure investment needs, whereas blue signifies that the required levies would be in excess of one (that is, investment needs exceed subsidies), and grey areas indicate countries for which no data are available. We only examine the case in which subsidies are redirected at the national level, that is, no redistribution across countries takes place (which does not seem politically feasible).

These results show that for the majority of countries in our sample, phasing out fossil fuel subsidies would free up enough funds to finance universal access to water, sanitation, and electricity. For instance, only slightly above 60% of the population have access to water in Nigeria. Although fossil fuel subsidies for this country (US$7.3 billion) are considerably lower than for other countries in our sample (but among the highest in Africa), a fraction of less than 4% would be sufficient to provide water for the entire population (Fig. 1a). However, for China, almost half of its fossil fuel subsides (US$9.8 billion per year) would be required, and for some countries, such as the Democratic Republic of Congo, Honduras, or Papua New Guinea, they would not be sufficient to cover investment needs. For sanitation, we find a similar picture (Fig. 1b). For instance, in Indonesia and Bangladesh, less than 60% of the population has access to improved sanitation, about 47% in Pakistan and 34% in India. At the same time, in 2011 these countries had fossil fuel subsidies of between roughly US$6 billion and US$30 billion. According to our estimates, investing a share of between 2% (Indonesia) and 18% (India) over a 15 year period would be sufficient to achieve universal access to sanitation in these countries. Likewise, almost 370 million people lack access to electricity in India, which could be provided by investments of less than 6% of this country's fossil fuel subsidies (Fig. 1c). For Bangladesh, more than 80 million people could gain electricity access for less than of 7% of current fossil fuel subsidies. For Nigeria, where more

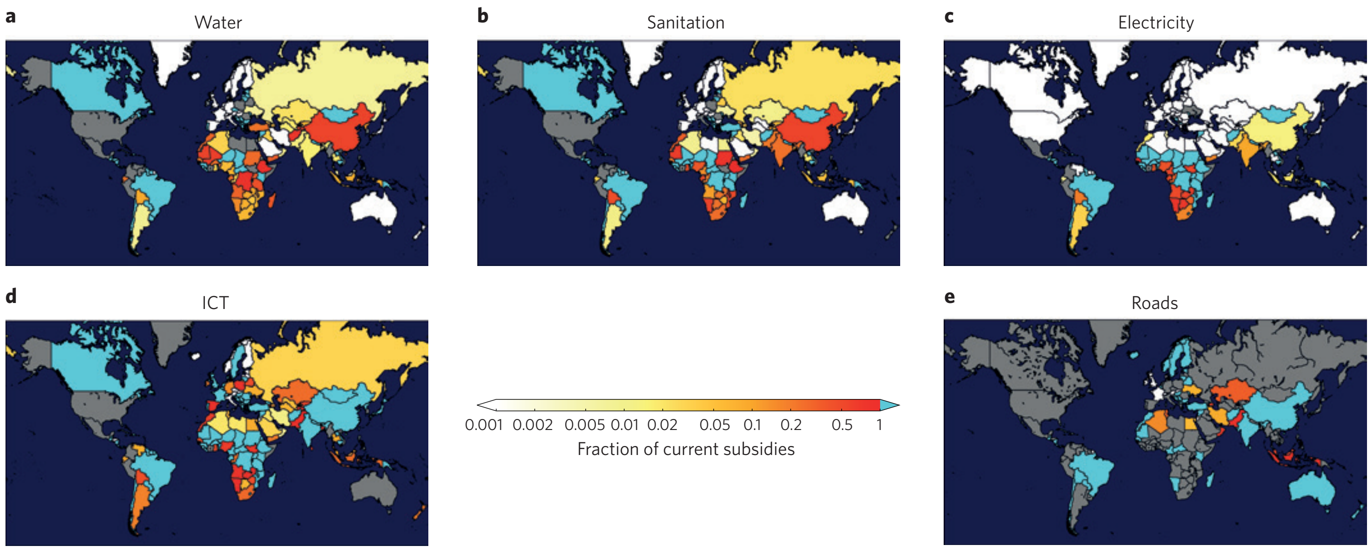

Figure 1 | Potential to achieve universal access to key infrastructures by 2030 through subsidy reform. We have assumed that without policy intervention fossil fuel subsidies would remain at their current (that is, 2011) levels. **a–e**, The share of fossil-fuel subsidies required to finance universal access to water (**a**), sanitation (**b**), electricity (**c**), telecommunication (**d**), and to pave all unpaved roads (**e**). Please note logarithmic scale. Grey areas indicate lack of available data.

than 140 million people are without electricity, however, almost half of fossil fuel subsidies would be required. Moving on to telecommunications, even countries such as Pakistan and Sri Lanka — where only about half of the population have access to telecommunication — could achieve universal coverage by redirecting their fossil fuel subsidies accordingly (Fig. 1d). However, for others, including India and several sub-Saharan countries, the investment requirement for telecommunication goes considerably beyond the savings that could be achieved by fossil fuel subsidy reform. Finally, while paving all unpaved roads would exceed the current level of fossil fuel subsidies for several countries and use up a large part of subsidy reform for others (Fig. 1e), it would be a feasible course of action for those countries that have high fossil fuel subsidies and already a high share of paved roads, such as Algeria, Egypt, Kazakhstan and Pakistan.

Our analysis indicates that redirecting fossil fuel subsidies to infrastructure investments could, at least for some countries, close a large share of current infrastructure access gaps, in addition to the indirect benefits of economic efficiency and environmental improvements. Although many of the countries that display the highest subsidies perform comparatively well in terms of access (for example, Saudi Arabia, Iran), and many of those with the largest access gaps have relatively low subsidies, there is a nexus of countries with high fossil fuel subsidies and large access gaps. This is particularly true for a number of African countries (including the Republic of Congo, Zimbabwe, Zambia, Cape Verde, Angola and Nigeria; see Supplementary Information for details). Given the large human-development benefits of these infrastructures[15,16], it seems likely that increased access could be sufficient to compensate for higher energy costs resulting from removal of subsidies. Nevertheless, a gradual decline of subsidies, as well as measures to begin building up infrastructure before subsidies are lowered, will need to be implemented. Otherwise, some people could be affected by higher energy prices without benefiting from increased access during the transitional period of infrastructure construction.

Highlighting the potential opportunity costs of fossil fuel subsidies — that is, the benefits that could be reaped if they were used in a different way — might strengthen the support for measures aiming to redirect these subsidies[17]. It could hence alter the political economy of fossil fuel subsidies by affecting the balance between interest groups supporting and opposing subsidy reform. As a result, linking fossil fuel subsidy reform to access considerations could turn out to be beneficial for development as well as the environment, and might even provide a viable basis for more ambitious climate change mitigation policies in the future[18]. How much benefit can be realized in practice arguably depends on country-specific factors, in particular the political influence of different interest groups and the possibility of forming coalitions in favour of subsidy reform. Future research will be required to explore opportunities for, and obstacles to, combining fossil fuel subsidy reform with infrastructure investment and to identify countries that are likely to be good candidates for the approach outlined in this paper. ❐

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Additional information
Supplementary information is available in the online version of the paper. Reprints and permissions information is available online at www.nature.com/reprints. Correspondence should be addressed to M.J.

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COMMENTARY:

Usefulness and limitations of global flood risk models

Philip J. Ward, Brenden Jongman, Peter Salamon, Alanna Simpson, Paul Bates, Tom De Groeve, Sanne Muis, Erin Coughlan de Perez, Roberto Rudari, Mark A. Trigg and Hessel C. Winsemius

Global flood risk models were developed to identify risk hotspots in a world with increasing flood occurrence. Here we assess the ability and limitations of the current models and suggest what is needed moving forward.

Global flood risk models (GFRMs) are now a reality[1–7]. More and more, these 'quick and not so dirty' methods[8] are being put to use by an increasing range of practitioners and decision-makers. The adoption of the Sendai Framework for Disaster Risk Reduction[9] and the Warsaw International Mechanism for Loss and Damage Associated with Climate Change Impacts[10] have made these efforts even more essential.

However, GFRMs have their limits compared with local-scale models[11], and there is often a mismatch between their actual ability and the envisaged use by practitioners. Modellers and users need to critically assess this discrepancy. We provide perspectives drawing from practical applications of global river flood risk models (Table 1), demonstrating the accomplishments in these examples, as well as limitations and gaps between user 'wish lists' and model capabilities. We present a research agenda to address these issues and reduce the gaps.

Applications in risk management

The global assessment reports (GAR)[4] of the United Nations Office for Disaster Risk Reduction provide a high-level platform for distributing global natural hazard risk data, including floods, which has proved instrumental in advocating for disaster risk management (DRM) internationally. Risk is framed as a 'contingent liability'; if a country allows future risks to accumulate, it effectively undermines its own potential for future socioeconomic development. This has paved the way for a more quantitative approach in the Sendai framework compared with the previous Hyogo Framework for Action, setting quantitative risk-reduction targets that are now being developed into measurable indicators.

GFRMs have been applied by the World Bank and the Global Facility for Disaster Reduction and Recovery to inform national-level DRM. Following Nigeria's devastating floods in 2012, a post-disaster needs assessment recommended strengthening flood resilience. In response, the World Bank Africa Disaster Risk Management team began developing a National Flood Risk Management Implementation Plan. At the time, little local or national information was available to assess flood risk. Within weeks, the GLOFRIS model[5,6] (Global Flood Risk with IMAGE Scenarios) was used to provide flood risk maps per state. These were used in dialogues to engage stakeholders and identify risk hotspots requiring further localized research. Building on this success, a first-cut state-level flood risk assessment was commissioned for World Bank's Europe and Central Asia region, including climate and socioeconomic projections. These rapid assessments in data-scarce countries have been useful in internal World Bank Group discussions and will be used in the near future to inform discussions with governments in the region.

With advances in numerical algorithms[12], new global datasets[13], and high-performance computing, it is now possible to develop global flood hazard models at 100 m resolution that solve hydrodynamic equations. An example is the SSBN-flow model[14], which has been used for national flood hazard mapping in Belize as part of the World Bank Caribbean Risk Information Programme. The Government of Belize will use the nationally consistent, indicative flood hazard maps to support decision-making in spatial and infrastructure planning, particularly for housing and roads, from national to enumeration area scales. This approach has considerably enhanced the quality of flood information, which was

Correction

In the Commentary 'Development incentives for fossil fuel subsidy reform' (*Nature Clim. Change* **5,** 709–712; 2015), in the Acknowledgements, J. Steckel's surname was incorrectly spelled. This has been corrected in the HTML and PDF versions after print 6 August 2015.