Assessing the costs of photovoltaic and wind power in six developing countries

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Abstract

To support developing countries in greenhouse gas (GHG) emission abatement the 2010 Cancun Agreement established various institutions, among others a financial mechanism administered by the Green Climate Fund (GCF). However, the instruments for delivering the support and the magnitude of different countries' financial needs are strongly debated. Both debates are predominantly underpinned by rather aggregate and strongly varying top-down cost estimates. To complement these numbers we provide a more fine-grained bottom-up approach, comparing the cost of the renewable energy technologies (RET) Photovoltaics (PV) and Wind in six developing countries with those of conventional technologies. Our results unveil large cost variations across specific technology-country combinations and show to which extent fossil fuel subsidies can negatively affect the competitiveness of RET. Regarding the instrument debate, our results suggest that in order to foster transformative changes, Nationally Appropriate Mitigation Actions (NAMAs) are often more suited than a reformed Clean Development Mechanism (CDM). Regarding the financial needs debate, our results highlight the need for a decision on a "fair" baseline calculation methodology. To this end, we propose a new methodology which incentivises changes in the baseline through subsidy phase-out. Finally, we contribute to the debate on domestic versus international support for these measures.

Key Words: Developing world, Economics, Policy, Energy

1 Introduction

Under the Kyoto Protocol, developing countries remain without GHG emission reduction obligations but are addressed by the CDM[1]. Despite the many lessons learned[2,3] in the nearly 3500 CDM projects registered in 70 plus countries[4], emission reduction efforts in developing countries need to be scaled-up massively in order to reach the 450 ppm CO_2-only target[5]. To this end, the Cancun Agreement establishes among others a financial mechanism aiming at “mobilizing jointly $100bn per year by 2020 to address the [mitigation and adaptation] needs of developing countries”[6, p. 15]. However many issues remain unresolved, of which we address two.

First, a debate over how to determine different countries’ financial needs for emission abatement, to be financed by developed countries, exists[7-9]. For instance, in the power sector, the biggest contributor to anthropogenic GHG emissions[10], renewable energy technologies (RET) have large abatement potential[11,12]. However, with few studies systematically comparing costs of RET in developing countries, there is “a striking dearth in reliable peer-reviewed data on what it costs to generate renewable electricity and what determines those costs”[13] on a global scale. Currently, the debate is mainly supported by top-down estimates on a very aggregate level. It is estimated, for example, that additional investments in RET of about €1.2tn from 2010 to 2030 (50% thereof in non-OECD countries)[14] and the coverage of their annual incremental costs at $27bn[15] are needed to reach the 450 ppm target. Furthermore, estimates vary strongly due to differences in assumptions and methodologies[8]. While such numbers are important for approximating total financial needs, more detailed data is needed to account for costs differing strongly across countries and technologies[16].

Second, which instruments are most effective for distributing financial resources in a post-Kyoto regime is heavily debated[17]. On the one hand, several major shortcomings of the CDM have been identified[18,19], spurring a discussion on CDM reforms such as differentiating technologies or countries[20] and up-scaling via “Programs of Activities” (PoAs)[18]. On the other hand, NAMAs – ”a set of policies and actions tailored to the circumstances of individual countries” – have received increased attention[17, p.32]. Proposed by the respective country but financed unilaterally and/or internationally, e.g., via the new financial mechanism[21], NAMAs fuel the hopes of higher emission reductions because they are able to induce “long-term transformative processes” [17, p.32]. Fine-grained analyses of the costs and potential of abatement options could also support this debate[18].

Most currently available bottom-up studies do not adequately inform the aforementioned debates for three reasons. First, the technologies’ costs in developing countries are discussed rather generically, neglecting important aspects of concrete country contexts[11,16,22]; second, they have a very narrow focus on a particular application (e.g., a project focus[23]), thus impeding comparative analyses of potentials and costs on a national or regional level, which is needed to fuel the instrument debate; or third, they are based on actual CDM project application data which might be biased since these projects need to “demonstrate that they are financially unattractive without the CDM revenues” [24, p. 213].

We address this gap by analysing the incremental costs of Wind and PV – two technologies with abundant natural potential[25] – in six developing countries. More specifically, we apply a consistent methodology comprising the following steps (compare Supplementary Figure 1): (1) calculation of the costs of electricity generation of the baseline power mix, (2) calculation of the cost of PV and Wind, (3) derivation of the RETs’ incremental costs of both electricity generation and emission abatement, (4) analysis of the effects of fuel subsidies on these costs. We conclude with implications for the aforementioned debates on financing needs and instrument choice.

2 The costs and emission baseline of electricity generation in developing countries

For our study, we chose six countries reflecting differences in country size, development status and baseline mixes (compare Figure 1 and Supplementary Note 1). With respect to the technology mix, the two largest countries, Brazil and India, are very heterogeneous and thus render an accurate analysis of the entire country impossible. We therefore focus on specific regions: In Brazil the north-eastern power grid region and in India, where power regulation is mainly enacted on the state level[26], the state of Karnataka (hereafter $Brazil_{NE}$ and $India_{KA}$). We calculate the generation cost and emissions for each of the six countries' electricity generation baseline mix (see Supplementary Tables 1 and 2 for the share and generation cost of individual baseline technologies underlying the mix in the different countries).

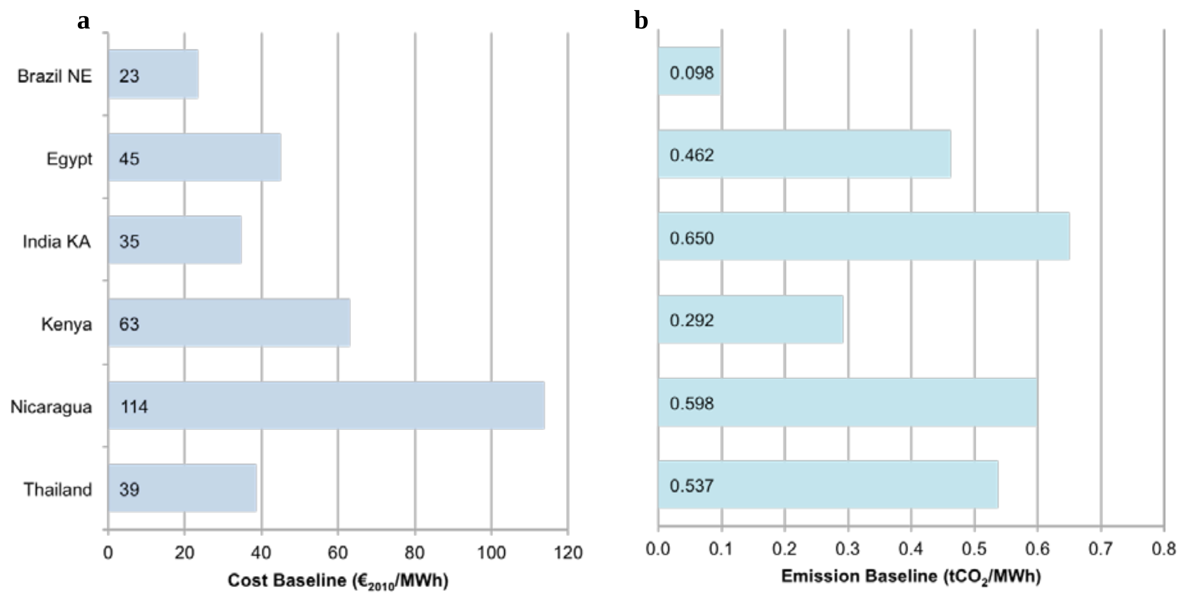

Figure 1 Overview of the generation cost and emissions of the baseline electricity generation mix. a, The costs in $€_{2010}$/MWh of electricity produced in 2010. **b,** The corresponding emissions in tCO_2/MWh of electricity produced in 2010. The difference of our results in India and Kenya to the results obtained in PDDs can be explained as follows: in India, we calculate the baseline exclusively for Karnataka, whereas PDDs use the entire southern Indian grid. In Kenya, PDDs use dispatch data to select the baseline technologies.

We follow the UNFCCC "combined margin" baseline approach, which reflects that RET would affect power generation from both existing plants and plants to be built[27], to select the baseline technologies. However, for calculating the cost of that baseline mix (for details see Supplementary Note 2 and Supplementary Tables 1-5) we deviate from current CDM methodologies in two important respects. First, instead of using the actual fuel prices, i.e., including fuel subsidies, we decided to follow an IEA approach[5] and use global, i.e., unsubsidised fuel prices (see supplementary Figure 2) in our model. This approach has the advantage of not favouring countries employing practices obstructive to climate change mitigation. Countries are not rewarded for fuel subsidies, which lower the cost baseline and thus result in higher incremental costs. Assuming unsubsidised prices therefore allows the comparison of countries' baselines on a level playing field. However, as private investors, who will need to finance most of the investments, consider fuel subsidies, we take subsidies into account farther back . Second, we consistently apply country specific discount rates (see Supplementary Table 6; Supplementary Figure 3 presents a sensitivity analysis on the impact of discount rates) – reflecting varying political and legal risks for private investors[28].

With cost differences of up to a factor of 4.9 (see Figure 1a) our results highlight the large heterogeneity between the countries' baselines. Kenya and especially Nicaragua stand out because their baseline mix consists to large parts of oil fired plants, a very costly fuel if unsubsidised. $Brazil_{NE}$ is found at the lower end as its baseline mix is dominated by hydro plants. With regards to emissions (see Figure 1b), we observe differences up to a factor of 6.6. $Brazil_{NE}$ exhibits a low baseline due to the dominance of hydro power in the generation mix, while $India_{KA}$ Nicaragua and Thailand have a high baseline due to a strong reliance on oil or coal plants. Kenya is in the middle as the above mentioned oil-based plants are complemented by emission free geothermal and hydro plants. The emission and cost baselines are not correlated, as for instance rather inexpensive technologies can have zero (e.g., hydro) or very high (e.g., hard coal) direct emissions.

3 The costs of renewable electricity generation

In order to calculate the cost of RET in a manner that allows a "fair" country-technology comparison, we set a 10% target share of national electricity production for each technology. While the CDM is project based, the introduction of such target share allows us to shed light on the rather domestic structural challenges that might need to be solved and thereby contribute to the instrument debate. The height of the share is deliberately chosen: On the one hand, this share exceeds a "technology penetration"[21, p. 41] necessary to build a local supportive business context that benefits from interactive learning between the relevant actors[29]. On the other hand, the share of intermittent RET is limited to such an amount in order to exclude major grid stability issues[30]. In order to represent private investor behaviour, we applied a search algorithm (compare Supplementary Note 3) so as to identify the most attractive sites for the instalment of RET in each country and again used country specific discount rates (see Supplementary Table 6). Based on accurate data (see Supplementary Tables 7 to 9) we calculate the levelised cost of electricity generation (LCOE) of RET, which can be used as an estimator for the necessary height of a feed-in tariff (FIT), a potential NAMA instrument with a proven track record of effectively leveraging private investments[21] (see Supplementary Equation 1 for a short discussion on using LCOE for RET). Finally, we performed a sensitivity analysis on grid connection costs (see Supplementary Table 10) as electricity grids are an essential pre-condition for the diffusion of large scale RET[31] (off-grid small scale RET exhibit very different economics and are not considered in this study).

Our results (see Figure 2) show that PV has generally much higher LCOE than wind in 2010 (between 2.2 to 4.5 times), mainly due to a lower amount of electricity generated per invested Euro. Though large cost reductions within the next ten years are expected, the LCOE of PV in 2020 remain much higher than those of wind (factor 1.7 to 3.4). Therefore, large-scale PV is rather a long-term option for emission abatement in developing countries. The relatively low cost reductions of wind make the 2010 numbers a good estimator for near term incremental costs against the baseline calculated above. For each technology we also observe differences across countries (up to a factor of 1.3 for PV and 1.8 for wind). In relative terms, these differences barely change over time. They are predominantly driven by varying solar or wind resources and discount rates, whereas the influence of the grid connection costs is relatively low. If the target is to meet 10% additional RET-based electricity production, from a cost perspective, only wind would be employed due to the large cost differences of PV and Wind (compare the site-specific numbers in Supplementary Table 11). This remains constant even for a 20% target (see sensitivity analysis in Supplementary Table 12).

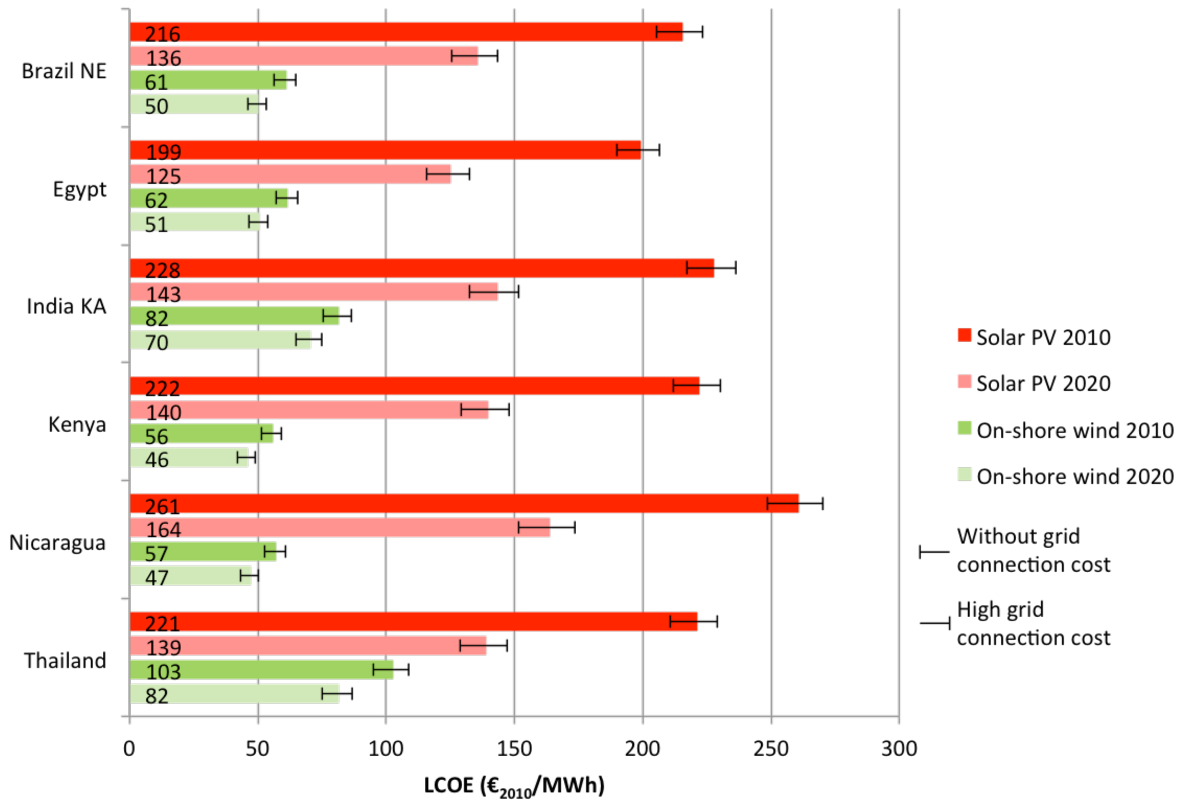

Figure 2 Overview of the levelised costs of electricity generation (LCOE) of solar PV and Wind in 2010 and 2020. The bars depict the LCOE (€$_{2010}$) of solar PV (red) and wind (green) at the 10% target share threshold, assuming average grid connection costs. The error bars represent the LCOE of state of the art technology (2010), the light coloured ones those of technology installed in 2020. The left end of the black stripes represents the LCOE without grid connection costs, the right end those with very high grid-connection costs.

4 The incremental costs of electricity generation and emission abatement

After having shown the large cost-variation of both the baseline and the RET we now turn to comparing their costs in two dimensions. First, we calculate the incremental costs of RET per MWh by subtracting the baseline costs from the RET costs. Second, we calculate the incremental costs per avoided ton of CO_2, synonymous with the nominal abatement costs or the carbon price needed in order to cover the incremental costs.

The incremental costs of electricity generation (Figure 3a) of PV are very high in all countries due to its hitherto high costs (compare Figure 2). As an aside, the incremental costs of PV can be much lower (or even negative) in off-grid applications, where the costs of the baseline technology (e.g., a diesel generator) are often very high[32,33]. Regarding wind, three groups of countries can be identified. In Brazil, India$_{KA}$ and Thailand the incremental costs are very high because of the low baseline costs and the relatively high wind costs in the latter two countries. The incremental costs in Egypt are much lower due to the higher baseline and low wind costs. In Kenya and Nicaragua, strikingly, the incremental costs of wind are negative as the high baseline costs by far exceed the costs of wind. The large differences between PV and wind in all countries, as well as the variation of wind across countries, highlight that the incremental costs are determined by the specific technology-country combination and not by either technology or country.

The incremental costs of emission abatement (Figure 3b) vary in a similar way with $Brazil_{NE}$ being an upward outlier due to its low baseline emissions. For PV they are very high in all countries. Regarding wind, the same three groups of countries emerge. While the emission-specific incremental costs in Egypt are roughly three times the 2010 average price of CDM credits on the spot market[34], those in $India_{KA}$ and Thailand and $Brazil_{NE}$ are significantly higher. Kenya and Nicaragua show negative abatement costs. At this point, one might ask why wind is not then strongly represented in the baseline mix of these countries. Here the role of fuel subsidies becomes important, which are examined in more detail in the section below.

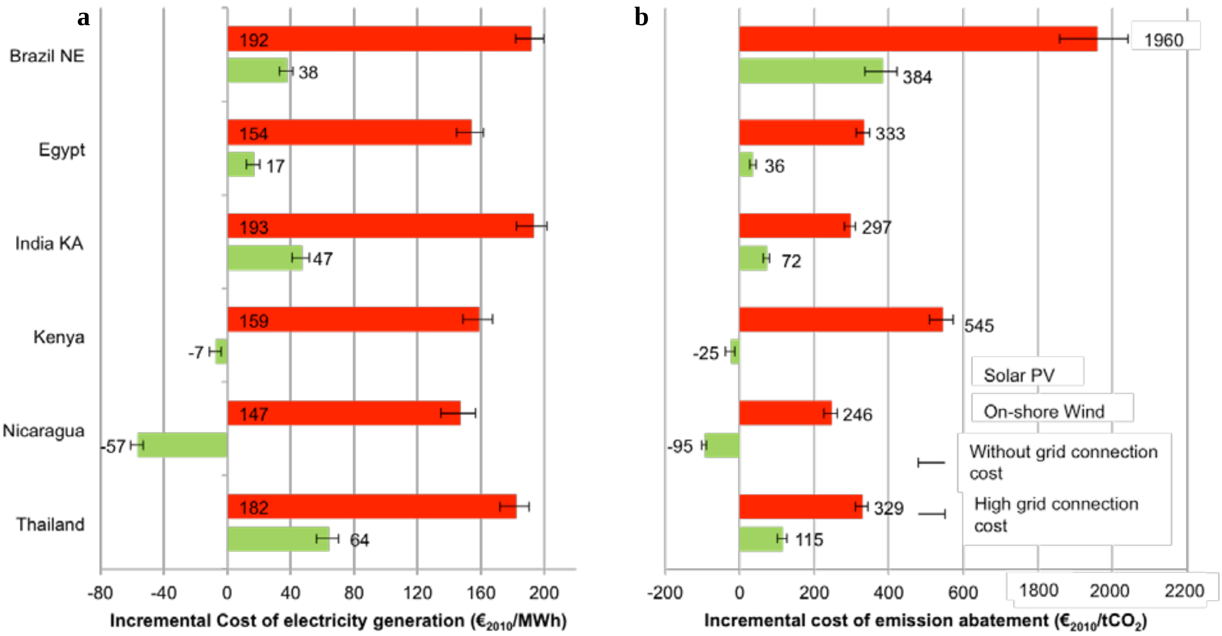

Figure 3 Overview of the incremental costs of electricity generation and emission abatement. a, b, The red bars depict the incremental costs of solar PV, the green bars those of wind. Again, the influence of the grid-connection costs is depicted by the error bars. **a,** The incremental cost of electricity generation in $€_{2010}$/MWh. **b,** The incremental cost of emission abatement in $€_{2010}/tCO_2$

5 The impact of fuel subsidies on the incremental costs of RET

So far, we have calculated the baseline costs, assuming no fuel subsidies, Despite the G20's efforts to phase them out global fuel subsidies were strongly rising in 2010[35]. They occur in many forms and can have major effects[35,36]. In order to quantify these effects, we compare the unsubsidized baseline costs with the subsidized baseline costs. We then calculate the incremental costs of RET against the subsidized and unsubsidized baselines. While we found evidence for large fuel subsidies in the power sectors of all six countries analysed (see Supplementary Note 4), our analysis is limited to $Brazil_{NE}$ and Egypt. Only here was fuel-specific subsidy data available, showing that power generators in both countries purchase natural gas from state-owned providers at about 50% of the global price (compare Supplementary Figure 2).

Our results (Figure 4) show to which extent fuel subsidies can "artificially" distort the competitiveness of RET. The negative leverage effect is most pronounced in cases where the costs of RET are relatively close to those of the unsubsidized baseline. In our study this is the case for wind in Egypt. While the fuel subsidies currently present in Egypt reduce the baseline LCOE by 33%, their effect on the incremental costs of wind is much higher: they increase by 88% in the presence of subsidies. Due to the higher incremental cost of wind in Brazil and PV in both countries, we do not observe such strong relative effects of fuel subsidies.

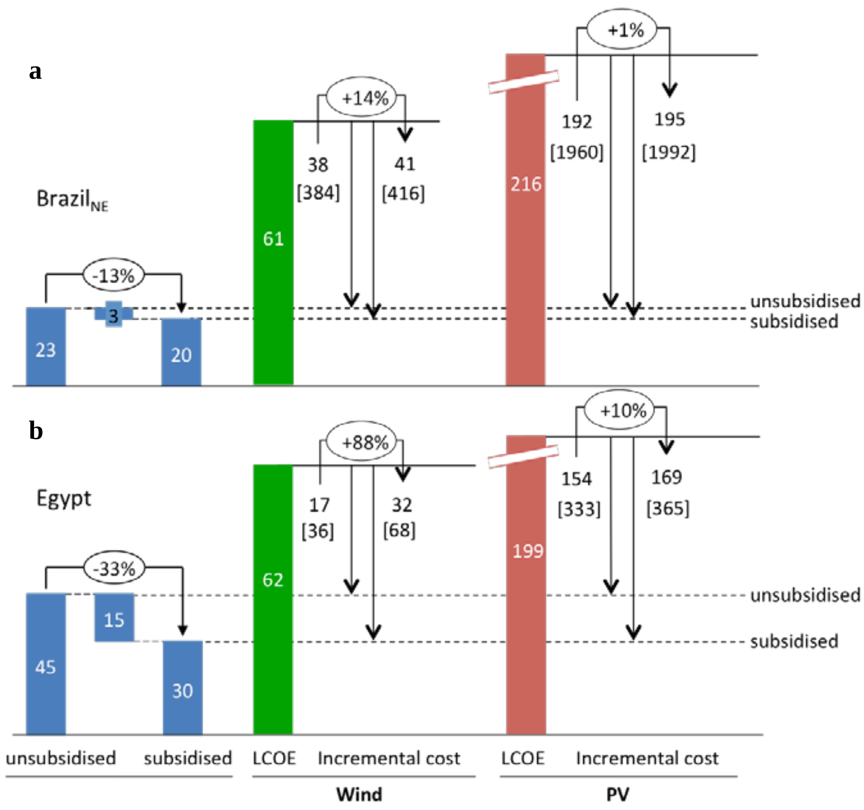

Figure 4 The effects of fossil fuel subsidies on the incremental costs of RET in Brazil$_{NE}$ and Egypt. a, b, The unsubsidized and subsidized baseline LCOE (blue) and compare them with the LCOE of wind (green) and PV (red). The resulting energy-specific incremental costs (in €$_{2010}$/MWh) are denoted next to the arrows. The numbers in brackets represent the respective CO_2-specific incremental costs (in €$_{2010}$/tCO_2). **a,** The case of Brazil$_{NE}$. **b,** The case of Egypt.

6 Implications for future climate policy and research

While our study sheds light only on a small proportion of emission abatement options in developing countries, it bears implications for the post-Kyoto debate. Below, we discuss the two results with the most important implications for the instrument debate and the financial-needs debate before we conclude with general remarks on NAMAs.

First, the large variation observed in the abatement costs support the proposals to reform the CDM via differentiation in the instrument debate. However the finding that the incremental costs strongly differ between specific country-technology (or even region-technology) combinations suggests that differentiation should be done on the basis of such country/region-technology combinations rather than by separating technology and country, as is currently being debated[18,20]. However, a centralised redistribution of credits on a country-technology- specific basis by the UNFCCC would be likely to increase the complexity of a reformed CDM and thereby raise its administrative costs and time requirements, for which the current CDM is already criticised[37]. By contrast, nationally designed NAMAs can address country-technology combinations well, e.g., via technology specific feed-in tariffs on a national (or even regionally differentiated) level, without requiring excessive expenditure in terms of administrative costs and time. However, the efficiency of NAMAs depends much more on the institutional capacity and size of the respective developing country than the CDM with its transparent governance structures[38,39]. For very small countries and those with relatively low institutional capacity, a reformed CDM might therefore be a more suitable instrument. In this context, Programs of Activities (PoAs) could represent a transitional solution as they allow for up-scaling the small-sized CDM and can be designed in a way that comes close to a NAMA but do not depend as much on the host country's institutional capacity[19,38].

For the financial-needs debate, the country-technology-specificity of incremental costs observed highlights the need for very fine-grained (bottom-up) yet replicable assessments on the technology and country level. Sometimes, as shown in the paper, a regional scope must be taken due to large country-internal variance. Approaches like the one presented in this paper are useful as they allow a country-technology comparison and can be adjusted, e.g., by choosing different target shares, and extended, e.g., to more technologies. In order to reduce the incremental costs of abatement technologies to a minimum, several instruments, such as FIT, low-interest loans or guarantee vehicles and investment subsidies, should be taken into account to calculate an ideal instrument mix for each country-technology combination. In an ideal world, central assessments of all countries and technology options (e.g., by the GCF) would be performed in order to arrive at a "fair" distribution of the financial mechanism funds (for our sample, the total cost of reaching the 10% target share and the private capital leverage potential are shown in Supplementary Table 13). In the real world this mind-boggling complexity might be eased to some extent by countries themselves prioritizing the measures that they consider most important from both an emission and a national development dimension. However, a demanding task remains to devise the right incentive schemes for NAMAs (see the final sentences of this article).

Second, our numbers show the potential negative leverage effects of fuel subsidies and reveal that tackling the baseline is a key issue for paving the way for large scale investments into abatement technologies in developing countries. Regarding the instrument debate, the CDM currently provides no incentive for addressing the baseline. It is questionable whether CDM reforms such as the introduction of sectoral baselines provide sufficient incentives to address the issue of subsidy reform. By contrast, through their more encompassing scope NAMAs can combine the support of abatement technologies with instruments addressing the baseline. Our results suggest that they could thereby leverage private investments into abatement technologies at much lower incremental costs from a global perspective.

Taking up these issues, the debate on determining financial needs should focus on the question of what constitutes a "fair" baseline for calculating the incremental costs which are to be covered internationally. We suggested that a starting point for this debate is the exclusion of fuel subsidies in the financial baseline. In theory, this implies that subsidy removal should be financed by the host country. In fact, one could argue that fuel subsidy removal is per Cancun Agreement definition a unilateral NAMA as subsidy removal does not involve explicit financial needs. However, fuel subsidies can often not be removed without negative consequences for the poor[36]. In sum, we suggest the following procedure to calculate the baseline in a "fair" and transparent manner: (a) all countries receiving international support must provide detailed reporting of the magnitude and type of subsidies; (b) as a general principle countries should only receive international support for incremental costs relative to the unsubsidized baseline; (c) for countries likely to exhibit strong "negative impacts [...] on social or economic sectors"[6, p. 13] from subsidy removal, the baseline calculation should start from the current subsidy levels but incorporate a dynamic subsidy reduction factor that encourages the phase-out of subsidies in the medium to long term.

In summary, our analysis suggests that NAMAs are more suitable than the CDM in order to achieve transformative changes in larger countries with a certain institutional capacity. However, it needs to be kept in mind that the distribution of funds to NAMAs will be subject to intense debates on parameters such as discount rates or equity considerations. Finally, NAMAs and their institutional implementation are still rather theoretical in nature while mechanisms such as the CDM have already been implemented, resulting in criticisms but at the same time an assurance to deliver a certain performance. Therefore, the classic project-based CDM, PoAs and NAMAs should be tailored to the right contexts and build on each other wherever possible.

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Contributions

M.S. and T.S.S. designed the research. T.S.S. and R.B. developed the model, carried out the data search and performed the analyses. T.S.S. and M.S. wrote the paper.