Feasible Mitigation Actions in Developing Countries

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Energy use is crucial for economic development but is the main driver of greenhouse gas emissions. Developing countries can reduce emissions and thrive only if economic growth is disentangled from energy-related emissions. Although possible in theory, the required energy system transformation would impose considerable costs on developing nations. Industrialized countries could bear those costs fully, but policy design should avoid a possible 'climate rent curse' with financial inflows having a negative impact on the recipients' economies. Mitigation measures could meet further resistance because of adverse distributional impacts as well as political economy reasons. Hence, drastically re-orienting development paths towards low-carbon growth in developing countries is overly optimistic. Efforts should focus on 'feasible mitigation actions' such as fossil fuel subsidy reform, decentralized modern energy and fuel switching in the power sector.

Today's developed countries account for the largest share of global greenhouse gas (GHG) emissions accumulated in the atmosphere. However, recent years have witnessed a rapid increase in developing countries' emissions, most prominently in China, which has not only become the world's largest emitter in 2006, but whose energy-related CO_2 emissions per-capita (7.1t) even though still below the OECD average, have almost reached the EU27 average of 7.4t in 2012.[1] If other developing countries follow China's carbon-intensive growth pattern, ambitious climate stabilization targets – such as the 2°C target agreed by the world community – are likely to become infeasible even if industrialized countries were to drastically reduce their emissions.[2]

Analyses with large scale integrated assessment models often conclude that mitigation costs for developing countries are relatively moderate.[3] Some recent studies have highlighted the potential positive effects of climate measures on economic growth[4–6] and the associated promise to create new economic dynamism by means of a 'green industrial revolution'.[7] Despite these optimistic assessments of the possibility to re-orient growth paths towards 'low-carbon development'[8], this

Perspective argues that – while possible in theory – it is fraught with considerable obstacles in practice due to the central role that fossil fuels have played and continue to play for economic development.

The remainder of this Perspective is organized as follows: First, we discuss the historic relationship between economic growth, energy use and CO_2 emissions in detail. The second part highlights major challenges to low carbon transitions in developing countries, concluding that one needs to be cautious in what can be expected with regard to low-carbon development there. Third, we discuss feasible mitigation actions, focusing on subsidy reform, decentralized modern energy access for rural areas and fuel switching in the power sector.

Economic Growth, Income Distribution, Energy Use, and Carbon Emissions

Socio-economic development in the past has been closely correlated to energy use.[9,10] As fossil fuels have traditionally constituted the major source of energy, there is also a close correlation between human development and GHG emissions.[11] No country has managed to achieve high levels of economic development without having crossed a threshold in final energy consumption of approximately 40 GJ per capita.[12,13] Only a fourth of these energy needs can be explained by subsistence needs like cooking or heating[14]; an important part of the threshold can be explained by energy needed to build up physical capital stocks, e.g. infrastructure.[15,16]

Even though per capita emissions in developing countries generally remain below the OECD average they have been catching up fast, in particular in China. Not only for China, but also for other newly industrializing countries, economic growth can clearly be identified to be the main driver of rising CO_2 emissions, especially for the 2000s.[13]. A significant share of these emissions are released for the production of goods and services that are finally consumed in developed countries.[17,18] However, observed flows of emission embodied in trade cannot be interpreted as a sign of 'outsourcing' of emissions, and it seems likely that developing countries' emissions would have experienced a sharp increase even without trade with industrialized countries.[19] This trend of rising emissions in developing countries is reinforced by a global 'renaissance of coal' that has led to an increasing carbonization of the global energy system.[13] This implies that the historical relationship between economic growth and energy use, which is pre-dominantly provided by fossil fuels, also seems to apply to countries that have only recently started to industrialize and which seem to replicate the patterns of energy use and emissions observed in the past in today's rich countries – albeit at an accelerated pace.[20] This is illustrated in Figure 1, which shows per capita CO_2 emissions against the log of per capita GDP (the log is chosen in order to make dynamics at low income levels visible). It is remarkable that this relationship is very similar for most countries. For instance, China's income-emissions trajectory very closely tracks the historical emissions of Korea, Japan or France at the same income levels. The heavy reliance on fossil fuels is, of course, related to their low cost (if one ignores their negative climate and environmental externalities such as emissions and air pollution), wide availability, and versatility to supply different energy needs in different sectors.[21,22]

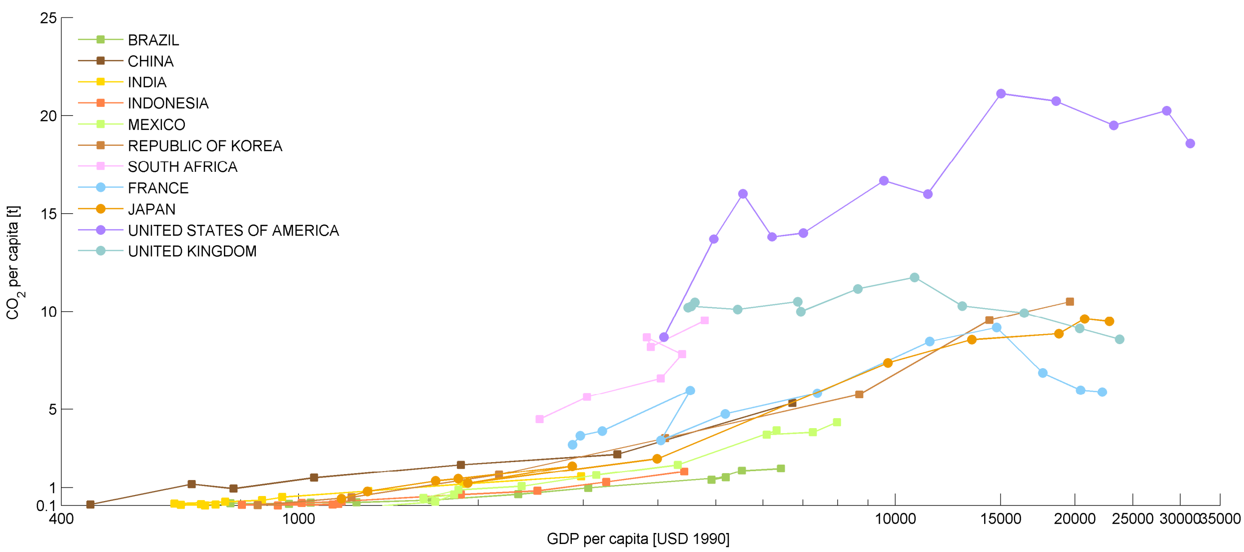

Figure 1: CO_2 emissions per-capita (ref [23]) over GDP per-capita (in 1990 int'l USD, ref [24]) for selected developed countries (circles) and selected newly industrializing countries (crosses) from 1900 – 2008 for 10 year intervals (when available). See also supplementary material for a more detailed description of the data.

Interestingly, similar patterns can also be found in studies investigating the carbon footprint of households at the micro level for selected developing countries. An Indonesian household with the income of the average European household exhibits a carbon footprint similar to that of the average European. Specifically, analyses for India, Indonesia and the Philippines show that richer households in these countries have considerably higher carbon footprints than poorer ones.[25–27] Figure 2 shows that for these three countries the relationship between (the log of) per-capita income and CO_2 emissions in a cross-section of households rather closely matches the macro-economic relationship between GDP and emissions over time. This suggests that income is the most important driver of variations of emissions over time and between households in developing countries (as it has been in developed countries in the past). It also implies that an emerging middle class, at least in middle income countries, will further drive substantial emission growth if energy systems are not significantly decarbonized, and that such a decarbonization should not be expected to happen automatically, but will very likely involve additional economic as well as political effort and associated costs.

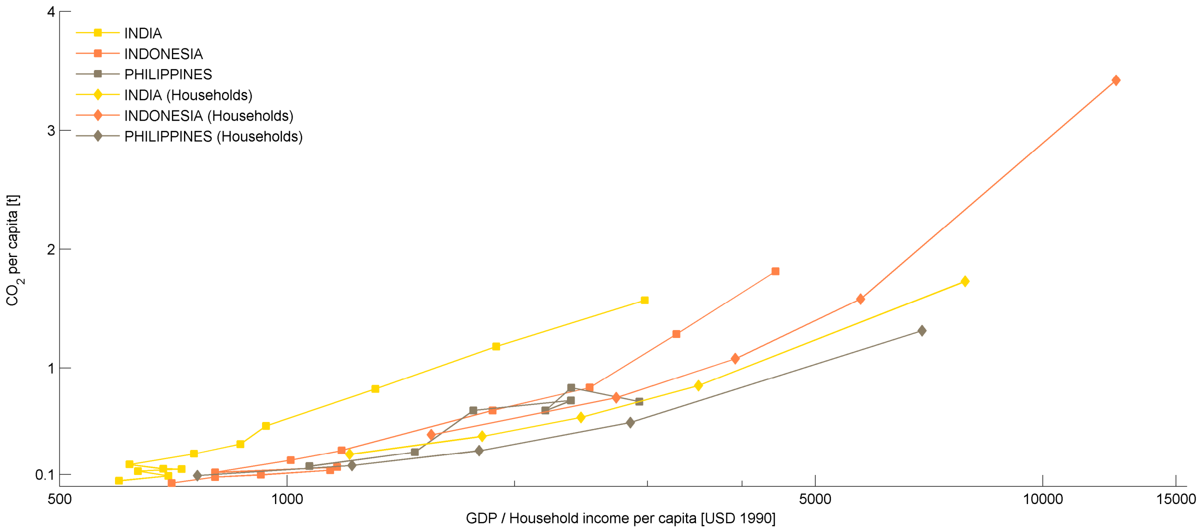

Figure 2: Combined micro and macro data for India, Indonesia and the Philippines. For household data income quintiles (with per capita emissions as the mean of households in the respective quintile) are shown, derived from ref [25] for India, ref [27] for Indonesia and ref [26] for the Philippines. Macro-economic data are

taken from ref [23] for CO_2 per capita and ref [24] for GDP per capita data showing data points for every 10 years from 1900 to 2008 (Philippines 1950 – 2008). See supplementary material for a more detailed description of the data.

However, empirical studies also suggest that at even higher levels of income, per capita emissions increase less than proportionally with per capita income.[26,27] That is, threshold effects, for example ownership of energy-intensive consumption goods including refrigerators, air-conditioners or cars at some income threshold, are likely to be present. Thus, high-inequality countries are not necessarily high per capita emitters. As shown by Grunewald et al. (ref [28]) income inequality is negatively correlated with per capita emissions, particularly in low and most middle income countries, suggesting a trade-off between inequality reduction and mitigation; in high income-countries, however, the correlation is positive suggesting that reductions in inequality can lower per capita emissions there (see also Figure SI 2 in the Supplementary Material).

Challenges to energy system transformation in developing and emerging countries

The evidence presented above suggests that developing and emerging countries cannot be expected to decarbonize their development paths anytime soon. These observations have three immediate implications. First, a drastic transformation of energy systems towards low-emission energy sources (such as renewable energy (RE), carbon capture and sequestration (CCS), or nuclear) would be necessary. Second, poor and emerging economies would need substantial financial support to cover the incremental costs of low carbon development paths, estimated to exceed USD 100 bln per year for a 450ppmCO_2-only target.[29,30] Third, the within-country differences in incomes, consumption patterns and carbon footprints have an important bearing on the emissions intensity of economic growth and, hence, on policies that may be able to reconcile social and GHG reduction objectives. In this section we will discuss a) the feasibility of large scale energy system transformations and thus emission reductions, b) potential financial transfers towards developing countries in the context of finance for climate change mitigation and c) political economy issues.

Emission reduction scenarios in developing countries

Given the strong link between energy consumption and economic development in the past, future growth of today's poor countries will require a large amount of additional energy. Steckel et al. (ref [15]) show that climate change mitigation scenarios implicitly assume that developing countries will not significantly increase their current levels of energy use. In the light of the results described above, keeping energy consumption constant does not seem possible, as energy will be required for basic needs, infrastructure and other consumption goods demanded by a growing middle class in today's developing countries.[31] At the same time, developing countries are expected to shoulder a large and rising share of global mitigation. In ambitious mitigation scenarios (IPCC category I + II, see ref [32]), the median share of emission reductions (compared to the business-as-usual scenario) taking place in developing (non-Annex I) countries is approximately 60% in the near term increasing to 70% at the end of the century, as shown by Figure 4.

a) Medium ambitious mitigation scenarios (IPCC category III + IV)

b) Ambitious mitigation scenarios (IPCC category I + II)

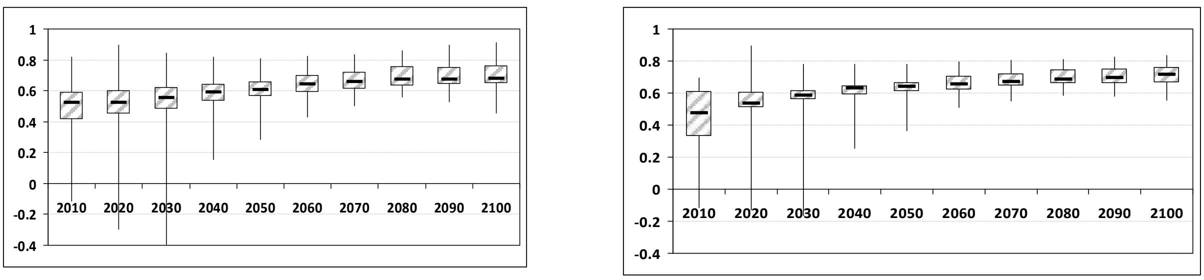

Figure 3: Percentage of global mitigation carried out by non-Annex I countries in differently ambitious climate mitigation scenarios compared to scenarios without climate mitigation in scenarios considered for

the IPCC SRREN (ref [33,34]). In total 131 different mitigation scenarios have been considered including second best (e.g. delayed participation or constrained technology) scenarios Boxes show the 25 – 75 percentile ranges, whiskers the maxima and minima and the bold lines the median. See also supplementary material for a more detailed description of scenario data.

Large scale adoption of low-carbon energy sources could allow increasing energy use without at the same time increasing emissions. RE is seen to be key in energy system transformations and it is shown to have the highest technological option value of low carbon energy technologies, i.e. forgoing an expansion of RE would result in a more pronounced increase in abatement costs than not having the possibility of expanding nuclear energy or CCS.[3] CCS, however, in combination with biomass is crucial for low-stabilization scenarios as it provides the possibility to generate negative emissions.[35] Today, RE accounts for only about 11% of energy use in developing countries of which the largest share is traditional biomass and hydro power.[36] While the potential for RE is usually seen to be large, it is often still more expensive than fossil fuels[33,37], particularly when taking into account costs of integrating variable renewable energy sources into the electricity grid.[38,39] Low institutional capacities and credit constraints also hinder the transformation of the energy system on a larger scale.[22,40]

On the micro energy level, RE using off-grid systems are often competitive today[41] and can contribute to fulfilling basic needs. However, such decarbonization of energy systems is linked to relatively high incomes, as highlighted by extensive cross-country and time-series research on 'energy ladders' examining how fuel choices are related to levels of socio-economic development.[42] For example, analyzing Kenyan households' lighting fuel choices suggests that there is a cross-sectional energy ladder, with a very high income threshold for modern fuel use – including solar energy use.[43] Furthermore, scaling up low carbon energy-supply to a level needed beyond fulfilling basic needs would probably impose additional costs on developing countries[21] and seems unlikely to result in deep structural economic transformations that could trigger massive productivity increases, as has been the case for the railroad or information technologies.[44] All this implies that much more action and support (including finances, technologies, and capacity-building) will be required to promote renewable energies in developing counties. Due to persistent energy shortages, legitimate energy access targets, and high economic growth, the cost of waiting until such support materializes is high[22], necessitating fast concerted action in order to avoid lock-in effects that would make a reorientation of energy systems more difficult and costly in the future.[45,46]

A climate finance curse?

It is widely acknowledged that developing countries should not be negatively affected by climate change mitigation, as e.g. reflected in the UNFCCC principle of 'common but differentiated responsibilities' (ref [47]). As a consequence, scenarios frequently assume that mitigation costs are shared globally according to an equitable burden-sharing scheme (e.g. emission certificates being allocated according to an equal per capita scheme) that results in transfers from developed regions and relatively low mitigation costs or even net gains for developing countries.[3] Propositions to establish a global carbon budget similarly imply considerable financial transfers, mostly for countries at an early stage of development.[48] Jakob et al. (ref [29]) estimate that financial transfers could - at least for those allocation schemes that are usually perceived to be the most equitable – largely exceed recipients' mitigation costs and reach almost USD 400 bln in 2020. For some regions they would be of a comparable order of magnitude as revenues from natural resource exports in the past.

Even if such sizable transfers to developing countries were politically feasible from the perspective of industrialized countries, their effect on recipient countries may well be less beneficial than expected, as they might negatively affect long term growth prospects, comparable to adverse effects observed for natural resource revenues.[49,50] The literature has identified several channels to drive this so-called 'resource curse', of which Dutch Disease, volatility, and rent seeking in combination with the quality of the institutional environment are most important.[51] Analyzing similarities between those channels, Kornek et al. (ref [52]) conclude that financial transfers for climate change mitigation could generally be comparable to resource revenues and hence have the potential to result in a 'climate rent curse'. While in theory these adverse effects could be alleviated by specific measures (such as sovereign wealth funds or appropriate fiscal and monetary policies), recipients often may not have the required institutions in place. Figure 4 shows indicators for 'rule of law' and 'control of corruption' exemplarily for institutional quality, ranging from -2.5 to 2.5 with higher values indicating a better quality of governance[53,54] for countries that would have received transfers if an 'equal per capita' allocation scheme had been in place in 2008, assuming per capita emission rights of two tons (see ref [7]) (note that we only consider energy-related emissions). Countries are ranked according to the share of the inflows in GDP. Countries that receive the highest transfers generally also score relatively badly (i.e. below 0) on institutional quality. With very few exceptions, countries that receive more than median financial inflows display institutional quality below zero (i.e. the upper right quadrant of Figure 4 is practically empty), hence, most of the countries receiving high inflows might indeed be at risk of suffering from a 'climate finance curse'. In addition, even though financial transfers are usually seen to facilitate participation of poorer countries in international climate agreements[55], potential recipients of climate finance could make it less attractive to participate in an international agreement when they take into account potential negative effects of financial inflows.[52]

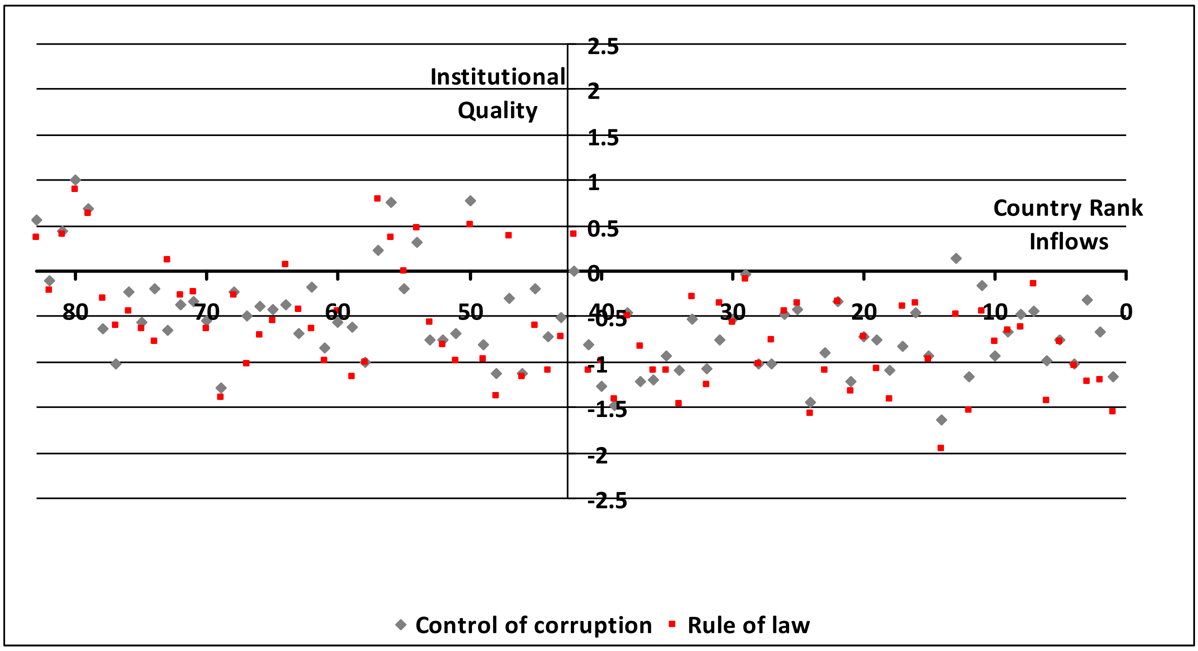

Figure 4: Indicators for 'control of corruption' and 'rule of law' ranging from -2.5 to 2.5, with higher values indicating a better level of governance (Data source: ref [54]; see ref [53] for a detailed description of how governance indicators are calculated) over countries with per capita emissions of lower than 2t in the year 2008, i.e. those would have received transfers if an international carbon market based on an 'equal per capita' allocation had been in place in 2008 (Based on data from ref [56]). Countries are ranked based on the share of financial inflows arising from climate finance in GDP (independent of a potential carbon price). See also supplementary material for a more detailed description of the data.

One obvious solution to address the possibility of a climate finance curse would be restricting the transfer of rents, e.g. by financial mechanisms that only transfer (the considerably lower) incremental investment costs for low-carbon technologies.[29,57] While attractive in principle, such schemes can be expected to turn out problematic due to the difficulty of establishing baselines and providing appropriate incentives for cost-effective emission reductions. Moreover, limiting the prospect of rent to be captured could also undermine developing countries' willingness to participate in these arrangements.

Income Distribution and Political Economy Issues

The relationship between household incomes and emissions discussed above suggests that countries in certain phases of economic development may face a trade-off: While on the one hand income growth for lower and middle income classes is desirable for many reasons (see ref [58]), such income growth pattern may lead to higher per capita emissions, mainly because of increased modern carbon-intensive energy use. As a consequence, the high carbon footprint of rich(er) households in developing countries would offer pathways to reduce emissions while simultaneously addressing income inequality through well-designed price and tax policies. However, such policies, which have the potential to increase aggregate well-being, can easily fall victim to power struggles that have a wide-ranging impact on economic performance and social stability. For instance, Rodrik (ref [59]) specifies how changes in the terms-of-trade (i.e. the prices of imports relative to those of exports) can result in a costly 'war-of-attrition' leaving everyone worse off, and Acemoglu and Robinson (ref [60]) show how technological advances that would be beneficial for society can be blocked by 'political losers' whose power base would be eroded by the change. It seems likely that these considerations also apply for distributional as well as political economy effects of policies to reduce emissions.

Feasible Mitigation Actions

As energy use is fundamental for economic development, and fossil fuels can arguably be expected to constitute the least-cost source of energy in most cases, it is not surprising that developing countries have so far refrained from entering internationally binding commitments to reduce their GHG emissions. Yet, several non-Annex I countries, including China, Mexico, South Korea and Vietnam have recently announced unilateral emission targets and the creation of emission trading systems.[61] According to Ostrom (ref [62]), a plausible explanation can be found in policy objectives that are not related to climate change, but that still contribute to mitigating GHG emissions as a co-benefit. For instance, in India energy security considerations rather than climate concerns likely drive energy system transformation[63], and in Vietnam, energy efficiency and economic restructuring are regarded as the central aim of recently adopted Green Growth policies.[64]

For this reason, we argue that in the short term mitigation in developing countries should be targeted at areas that promote important development objectives, such as improving energy access and energy security, reducing local air pollution, and increasing economic efficiency. In addition, mitigation actions in developing countries need to be feasible along three dimensions. First, politically, as most mitigation options create winners and losers and may require potential losers to be compensated and public opinion mobilized; second, institutionally, as many mitigation measures require fairly sophisticated institutional and administrative capacities (for example feed-in-tariffs, cap-and-trade systems or the participation in international mechanisms like REDD+); third, financially, as resource needs for mitigation efforts can be substantial, for example when thinking of upfront investments of some energy technologies. From this set of feasible measures those that have the largest potential to avoid or mitigate lock-ins into carbon-intensive development paths should be prioritized.

In the following, we discuss fossil fuel subsidy reform, decentralized modern energy for rural areas and fuel switch in the power sector as examples of feasible mitigation options. A full assessment of their political, institutional, and financial feasibility is not only beyond the scope of this article, but also subject to a multitude of country-specific factors. However, previous assessments of mitigation options have highlighted the potential of these options to promote human development while at the same time reducing emissions. While focusing on large emitters such as China, India, South Africa and Indonesia could be the most straightforward way to achieve emission reductions, feasible mitigation actions could also contribute to limiting increases in countries such as Vietnam or Nigeria, which are at an earlier state of economic development but whose emissions are expected to rise sharply in the near future.

Fossil Fuel Subsidy Reform

Low fuel prices cause important external effects, such as high local air pollution and related health effects. In the transport sector, which accounts for the second largest share of emissions in developing countries and growing fast[65], the costs of congestion add to these effects.[66] For the case of Beijing, Creutzig and He (ref [67]) estimate that currently the social costs of congestion as well as health impacts each amount to more than 3% of regional GDP. Yet, not only do governments fail to internalize these effects; fuel subsidies are still commonplace and impose high costs on state budgets. For instance, in 2011 Iran spent roughly USD 65 bln on subsidizing energy consumption, India about USD 34 bln and China about USD 20 bln (ref [68]). The economic distortion (i.e. the deadweight loss) related to subsidies for transport fuels (gasoline and diesel) have been estimated to amount to USD 44 bln per year in the ten countries with the highest subsidies.[69] Furthermore, fossil fuel subsidies have been found to be regressive in the sense that the largest benefits often accrue to rich households.[70] However, distributional effects strongly depend on the underlying energy type and existing tariff structure. If increasing block-tariff systems are designed as a pro-poor pricing instrument In the electricity sector removing subsidies can lead to substantial income losses for the poor.[71] Phasing-out fuel subsidies – or even starting to tax fossil fuels – would be highly effective. In a meta-review of studies from industrialized as well as developing countries. Brons et al. (ref [72]) estimate a price elasticity of -0.84 for transport fuels. That is, a 20% price increase resulting from lower subsidies or a tax would decrease fuel consumption (and hence associated emissions) by about 17%. By considerably decrease fuel consumption, fuel tax reform would hence improve air quality as well as energy security, provide direct economic benefits and also alleviate pressure from tight government budgets. In terms of climate benefits, the IEA (ref [2]) estimates that a complete phase-out of subsidies for oil products would reduce global GHG emissions by about 4.4% per year by the year 2020.

Despite these significant benefits of subsidy reform, fuel subsidies of different kinds are still a common policy instrument throughout the developing world, with powerful interest groups blocking reforms.[73] This implies that there is scope for increasing support for fuel subsidy reforms by better communicating the abovementioned benefits and lobby against such vested interest[74] (with a stronger role for the civil society, possibly supported by the international community. Furthermore, even if the effects of reforms were progressive (and more so if they are actually regressive), removing subsidies without providing appropriate compensation would actually leave the poorest part of the population worse off.[75] For this reason, it is crucial to establish appropriate compensation schemes that avoid adverse development outcomes and ensure buy-in of affected stakeholders. Good example for successful compensation mechanisms include lump-sum cash transfers (Iran and Georgia) increasing public expenditures that benefit low-income households (Indonesia, Niger, and Ghana) and strengthening social safety nets (Indonesia, Jordan, Moldova).[76,77]

Administering well-targeted compensation programs may be the most challenging component of a policy package of fuel subsidy cuts and compensatory policies, since the subsidy reform itself – or the introduction of fuel taxes – does not require highly developed institutional capacity.

Decentralized Modern Energy for Rural Areas

Globally, about 1.4 bln people lack access to electricity, and almost 2.7 bln rely on traditional sources of fuel[2], in particular biomass, for heating and cooking. This creates substantial health impacts, estimated to amount to more than 1.6 million deaths and over 38.5 million disability-adjusted life-years in the year 2000.[33] In poorer countries or remote rural areas, off-grid low-carbon energy sources, for example solar home systems or pico-hydro power stations, can be economically viable solutions to provide modern energy access.[41] Although measures to ensure access to clean cooking fuels, such as increased provision of LPG stoves, may under some circumstances raise emission, this increase appears to be negligible[78], in particular when having in mind that energy demand in developing countries has been largely met by increased coal use in recent years.[13] It seems likely that grid-based electrification would mostly imply expansion of carbon-intensive fossil technologies.

Fostering decentralized energy access might be primarily motivated from a development perspective, but may nevertheless offer significant emission reduction potentials.[79]

Achieving total rural electrification and universal access to clean-combusting cooking fuels and stoves will require substantial additional energy system investments, estimated to amount to about USD bln 65-86 per year.[78] Arguably, most developing nations will not be able to meet these financing needs from their budgets, regardless of the associated development benefits. Rather, at least some part of it will have to be provided by climate finance. In view of the fact that energy access is increasingly acknowledged as a fundamental cornerstone of the Millennium Development Goals[80] and initiatives such as the UN's 'sustainable energy for all' [81], some progress on this account seems to be within reach. In addition, recent research has made advances in identifying 'best practices' with regard to business models for off-grid electricity supply and their relationship to public policies.[82]

Fuel Switch in the power sector

Local air pollution is a wide-spread concern in many developing countries, in particular in regions that to a large extent derive their energy consumption from coal, which is associated to emissions of SO_2 and particulate matter (PM). In 2005, 89% of the world's population (especially in East Asia) lived in areas where the World Health Organization Air Quality Guideline for PM2.5 was exceeded.[83] In the year 2013, PM2.5 levels were more than five times the WHO annual maximum level in 58 Chinese cities.[84]

These emissions, and the related health concerns, could be mitigated by a switch to either renewable energy, nuclear, or natural gas, which at the same time are either carbon-free, or less carbon-intensive than coal. Some authors point out that the co-benefits of air quality improvements resulting from measures to reduce greenhouse gas emissions would be of comparable magnitude or even above their associated climate benefits. In a meta-analysis of co-benefits of air quality improvements resulting from climate change mitigation scenarios for 13 studies on developing countries, Nemet et al. (ref [85]) report a range of USD 27-196/tCO2, with a mean of USD 81/tCO2. In a similar vein, West et al. (ref [86]) point out that in their model calculations in the year 2030 health co-benefits in East Asia are 10–70 times the marginal abatement costs for the RCP4.5 stabilization scenario.

Even though it is conceivable that these health benefits could also be achieved by less costly technical solutions – such as installing scrubbers in existing coal power plants – they have to be evaluated in combination with other benefits (e.g. increased energy security) in order to provide a full picture.[87] In any case, reducing coal consumption can be expected to have an important part to play for reaping these co-benefits, due to its significant mitigation potential and its high intensity of emissions of SO_2 and PM per unit of final energy generated. This is in line with the currently introduced 'Action Plan for Air Pollution Prevention and Control' in China. Although mainly aimed at improving ambient air quality, if properly implemented it could result in declining CO_2 emissions from 2020 onwards.[84]

Other measures

The examples above are not intended to provide a comprehensive list of options. In different contexts, other mitigation options might either provide higher benefits or enjoy a higher degree of political or institutional feasibility. To illustrate the heterogeneity and complexity of possible combinations of feasible mitigation actions we briefly discuss three additional policy areas and instruments, namely agriculture, public transport, and international 'non-climate' agreements.

For some countries important mitigation options can be found in the agricultural sector, which accounts for about 10-12% of global GHG emissions, predominantly in the form of nitrous oxide and methane[88] and is thought to be responsible for 80% of deforestation and forest degradation, which is an important source of CO_2 emissions.[89] The largest share of the emission reduction potential in agriculture – which according to UNEP (ref [90]) lies between 1.1 and 4.3 $GtCO_2$-eq. per year – could be reaped by means of conservation tillage, combined organic/inorganic fertilizer application, adding biochar to the soil, improved water management and reducing flooding and fertilizer use in rice paddies.[91] These measures could be attractive for numerous reasons other than reducing GHG emissions, including increased agricultural productivity, reduced costs for fertilizer input[90], alleviated soil erosion[91] and improved water management.[92]

The introduction or expansion of more public transport can also provide considerable benefits in terms of less congestion, reduced local air pollution and increased safety. In contrast to fuel subsidy reform, public transport infrastructure can, however, put considerable pressure on government budgets; also the political economy of expanding urban public transport can be challenging.[65] While financially, politically, and institutionally more demanding, the benefits of improved public transport can be substantial (see ref [93] for the case of Taipei). Very importantly, such policies can avoid lock-ins by preventing urban sprawl and achieving a more compact urban form[94], which, in turn would result in substantial emission reductions as an ancillary benefit in the long run. Seeking low-cost context-adapted solutions, such as enforced fast-lanes for buses and including private operators into planning, would certainly increase the feasibility of mitigation actions for urban transport.

Finally, regional trade and integration agreements could become a vehicle to further promote a mitigation agenda. Regional trade agreements that go beyond trade liberalization and include environmental provisions have been found to reduce absolute emission levels in signatory countries.[95] Implementing those agreements is not primarily motivated by mitigation, but environmental provisions are often included to prevent a race to the bottom in environmental standards between trading partners.[96] Regional trade agreements have been the most popular form of trade liberalization in recent years.[97] Combining them with strong environment provisions, measures to spur technology transfer and capacity building could lower mitigation costs and alleviate concerns of emission leakage for all participants.[98] Hence, such agreements could provide another entry point for furthering an ambitious global mitigation agenda.

A step-wise approach for low-carbon development

Our analysis points to a major dilemma for global climate policy: While mitigation of GHG emissions in developing countries will be essential in any effort to limit global warming, economic growth is closely related to the use of fossil fuels, and spontaneous leap-frogging to less carbon-intensive development paths seems highly unlikely. Yet, requiring developing countries to forgo economic growth and put their development goals at risk is clearly neither defensible nor feasible. However, measures that address poor countries' development priorities and at the same time reduce GHG emissions could constitute feasible mitigation actions. We hence stress the importance of development benefits and propose to prioritize options that avoid lock-ins into carbon-intensive development paths, while explicitly considering each option's political, institutional and financial feasibility.

This Perspective has exemplarily discussed a number of issue areas – with a focus on fossil fuel subsidy reform, decentralized modern energy for rural areas, and fuel switch in the power sector – that could meet the above requirement of achieving emission reductions as a co-benefit. Such measures alone are probably not sufficient to achieve the globally cost-optimal emission trajectory and might even render the most ambitious stabilization targets – such as the 2°C target – difficult to achieve. However, they could form the building blocks of a future system of loosely coordinated climate agreements, which could promote technological innovation and change the political landscape to pave the way towards a gradual expansion of such initiative resulting eventually in an ambitious global mitigation agenda.[99]

The systematic identification of feasible mitigation options, whose mix will obviously differ considerably between countries, should be closely aligned with the process of formulating 'nationally appropriate mitigation actions' (NAMAs, see ref [100]), which could be supported by the Green Climate Fund and bi- and multi-lateral donors, such as the World Bank or the GEF. In addition, donors have already begun to mainstream climate change into their aid portfolios, which should give some impetus to reducing emissions in areas not primarily targeted at climate change mitigation.

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