Development perspectives of Sub-Saharan Africa under climate policies

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Abstract

Reduction of global greenhouse gas emissions at acceptable costs requires the inclusion of developing countries into a climate policy regime because their emissions grow rapidly. At the same time, less developed countries fear to suffer in terms of economic growth and domestic wealth. This study focuses on Sub-Saharan Africa as the region with the lowest income per capita and demonstrates how it could benefit from joining an international climate agreement without delay. Based on a scenario analysis with the Integrated Assessment model REMIND, we estimate the economic costs and transformation needs under different assumptions on the climate stabilization target, cooperation and technology diffusion. From simulation results it turns out that direct costs of climate policy will be up to 3% of aggregate consumption for Sub-Saharan Africa under a global tax regime. The indirect effect of emission permit sales (under a cap-and-trade system with acknowledged equity principles) and sales of biomass, however, are likely to be larger than this loss. The net effect of climate policy could very well be positive for the region. Results furthermore show that climate policies induce a shift towards higher electricity shares that are likely in favor of the poor.

1. Introduction

Does climate policy slow economic growth of Sub-Saharan Africa? The answer to this question will determine the incentives of this world region for participation in future climate policy. Large renewable energy potentials (e.g. solar energy) and international technology diffusion could ease the transformation towards a low carbon economy and facilitate the adoption of emission reduction commitments. However, following a traditional growth path fueled by fossil energies might be less expensive, hence increasing consumption or investment possibilities for other parts of the economy. Finally, depending on the degree of burden sharing in an international agreement, Sub-Saharan Africa might benefit from international transfers in excess of its mitigation costs. This paper provides a quantitative assessment of costs and opportunities and finds that Africa might benefit from climate mitigation policy even in non-environmental terms, provided that international climate policy includes some degree of burden sharing.

The literature on climate economics provides indication that climate stabilization goals can be achieved with moderate GDP losses (e.g. Kriegler et al., 2014). However, this is mainly based on a global assessment. There are only a few integrated assessment studies that investigate regional growth impacts (Tavoni et al., 2014, Aboumahboub et al., 2014, Luderer et al., 2012, Leimbach et al., 2010 and Lüken et al., 2011) and there is hardly any study on climate change mitigation that focuses on the less developed regions. Calvin et al. (2013) analyze the effect of African growth on future global energy demand and emissions under different baseline and climate policy assumptions, but do not quantify the feedback of climate policy on economic growth. Furthermore, the finding of moderate mitigation costs on a global level depends on a number of assumptions, e.g. universal climate policy regimes and world-wide availability of low-cost carbon free technologies.

This paper investigates the linkage between climate policy and future growth of Sub-Saharan Africa under different assumptions on cooperation and burden sharing. Including developing regions into international climate policy requires support for their economic development. Fair burden sharing matters (Raupach et al., 2014, Den Elzen et al., 2010) as well as technological cooperation (Golombek and Hoel, 2011). Emission reductions at low cost require technical progress directed towards emission savings and international technology diffusion. Directed technical progress and technology diffusion enable economic growth and the necessary emission reductions at the same time, and allow development patterns distinct from past experiences. Thus, today's low income countries can develop along growth pathways that require less energy but deliver similar wealth compared to today's high income countries. This study confirms the important role of technology diffusion. While technology cooperation gains additional importance when international climate policy is delayed, we also find that Sub-Saharan Africa may benefit from delayed cooperation. This is not only due to the reduction in short-term abatement costs but also due to increasing biomass prices in the long term.

Climate change is expected to hit low income countries hardest as they are more vulnerable and at the same time less capable to adapt to adverse climate change impacts. Respecting their legitimate interest to increase material wealth and opening the way for them to join the global coalition of countries that strive to stop climate change is a challenge. Normatively, given the historical responsibility for climate change, putting an additional burden on the shoulders of the poor is unfair. Without enhancing global equity, greenhouse gas emissions will not significantly be reduced. Baer et al. (2008) argue that the impasse of climate policy "arises from a severe, but nevertheless surmountable, conflict between the climate crises and the development crises". Poverty reduction and climate stabilization must go hand in hand. While this study shows partial benefits to Sub-Saharan Africa from delayed action, given the risks of climate change for Africa, a strategy of "develop first, care for the climate later" seems to be no option.

The summary for policy makers of working group II of the Intergovernmental Panel for Climate Change (IPCC, 2014) describes the most important climate impacts for each region. According to this, a 4°C warming would imply for Africa with very high probability a) compounded stress on water resources and exacerbated drought stress, b) reduced crop productivity with strong adverse effects on food security and c) changes in the incidence of vector- and waterborne diseases. It is not known how exactly these threats increase with temperature. To account for this uncertainty, we conduct a cost effectiveness analysis for limiting the CO_2 concentration both to 450 ppm or 550 ppm. This study shows that immediate global policy does provide benefits to Sub-Saharan Africa not only due to less implied climate damages but also due to less economic costs of mitigation by a novel permit allocation regime that respects the idea of equal per capita allocations in ambitious climate stabilization scenarios. While direct costs of climate policy will be up to 3% of consumption for Sub-Saharan Africa under a global tax regime, the indirect positive effect on consumption possibilities of emission permit sales and sales of biomass in a cap-and-trade regime are likely to be larger than this loss.

Within this study, we measure growth impacts either as consumption loss in a climate policy scenario as compared to a reference scenario, or as a need of energy system transformation. The latter may imply temporary changes in the consumption path or distributional effects that both are not visible in aggregated macro-economic figures. Distributional effects can for example be expected with increasing energy prices and expenditures (Jakob and Steckel, 2013) which account for a comparatively large share in household expenditures in less developed countries. We find that distributional effects under climate policy in Africa are likely in favor of the poor: Climate policy triggers a strong shift in final energy sources from liquid fuels to electricity, the prices of which prices will grow much slower under climate policy than the prices of liquid fuels.

Based on analysis with the Integrated Assessment Model REMIND we explore global mitigation challenges and quantify the economic cost of the transformation towards a climate-friendly global energy system. Our results are in line with a branch of literature that has an optimistic view on technology diffusion finding that energy-related transitions in developing countries occur earlier, faster and more simultaneous (Marcotullio and Schulz, 2007) than historically observed in today's rich countries.

In going beyond the existing literature on the integrated assessment of climate change mitigation, we do not only provide regional mitigation costs, but put a particular focus on the poorest world region – Sub-Saharan Africa (without South-Africa). We identify conditions and climate policy settings that help less developed countries to meet their development goals while managing the energy system transformation. Collier et al. (2008) point out two major ways in which Africa would benefit from international climate change mitigation: revenues from carbon permits and low-carbon technology provided by industrialized countries. Collier and Venables (2012) emphasize that Africa is well positioned to decarbonize it's energy system as it is well endowed with hydro and solar power potentials. In addition, they identify a latecomer effect: Since Africa has invested relatively little in energy production so far, they are not suffering from a lock-in in carbon-intensive energy supply technologies and can set up their system using renewable energy sources from the start. All of these effects are represented in the REMIND model, so that we are able to quantify them (Pietzcker et al., 2014). While it turns out that Sub-Saharan Africa is able to meet the transformation needs in general, the scenario analyses also indicates implied challenges like the massive increase of power supply capacities and the short-term increase of energy prices.

The paper is structured as follows. In Section 2 we give a brief description of the applied model and the scenarios which will be explored in the following sections. Scenarios are designed along the dimensions of ecological efficiency, co-operation and fairness. The discussion in Section 3 focuses on the comparison of economic costs Sub-Saharan Africa is confronted with in the different scenarios. The analysis also addresses distributional impacts of different burden sharing schemes. The mitigation scenario analysis continues in Section 4 with an exploration of the requirements of energy system transformation and an ex-post analysis of distributional effects that are potentially linked to this transformation. We end with some conclusions in Section 5.

2. Model description and scenario implementation

2.1 REMIND

REMIND is a global, multi-regional, energy-economy-climate model (Leimbach et al. 2010) applied to long-term analyses of climate change mitigation (e.g. Bauer et al. 2012, Luderer at al., 2013). A detailed model description can be found at http://www.pik-potsdam.de/research/sustainable-solutions/models/remind.

The macro-economic core of REMIND is a Ramsey-type optimal growth model in which inter-temporal global welfare is maximized. The model computes a unique Pareto-optimal solution that corresponds to the market equilibrium in the absence of non-internalized externalities. The world is divided into 11 regions: five individual countries: China (CHN), India (IND), Japan (JPN), United States of America (USA), and Russia (RUS), and six aggregated regions formed by the remaining countries: European Union (EUR), Latin America (LAM), Sub-Saharan Africa without South Africa (AFR), Middle East/North Africa/Central Asia (MEA), other Asia (OAS), Rest of the World (ROW). Trade in final goods, primary energy carriers, and in the case of climate policy, emissions allowances is explicitly represented. Macro-economic production factors are capital, labor, and final energy. The macro-economic core and the energy system module are hard-linked ensuring simultaneous equilibria on all energy and capital markets. Economic activity results in demand for different types of final energy (electricity, solids, liquids, gases, etc.) differentiated for stationary and transport uses. Final energy demand is determined by a production function with constant elasticity of substitution (nested CES production function). The energy system module accounts for endowments of exhaustible primary energy resources as well as renewable energy potentials. More than 50 technologies are available for the conversion of primary energy into secondary energy carriers as well as for the distribution of secondary energy carriers into final energy. Techno-economic parameters (investment costs, operation & maintenance costs, fuel costs, conversion efficiency etc.) characterize each conversion technology. They essentially determine future technology choice and energy mix. The model accounts for CO_2 emissions from fossil fuel combustion and land use as well as emissions of other greenhouse gases (GHGs). For numerical reasons, a reduced form climate module is used to translate emissions into changes of atmospheric GHG concentrations, radiative forcing, and global mean temperature.

In its baseline setting, REMIND is calibrated to generate a GDP trajectory that reproduces the SSP2 GDP scenario (Dellink et al., 2014). Accordingly population and labor force input is derived from SSP2 population scenario (KC and Lutz, 2014). Figure 1 shows the substantial increase of GDP and the peaking of the global population. Sub-Saharan Africa’s share increases in both categories – from 1% to 13% regarding GDP and from 10% to 25% regarding population.

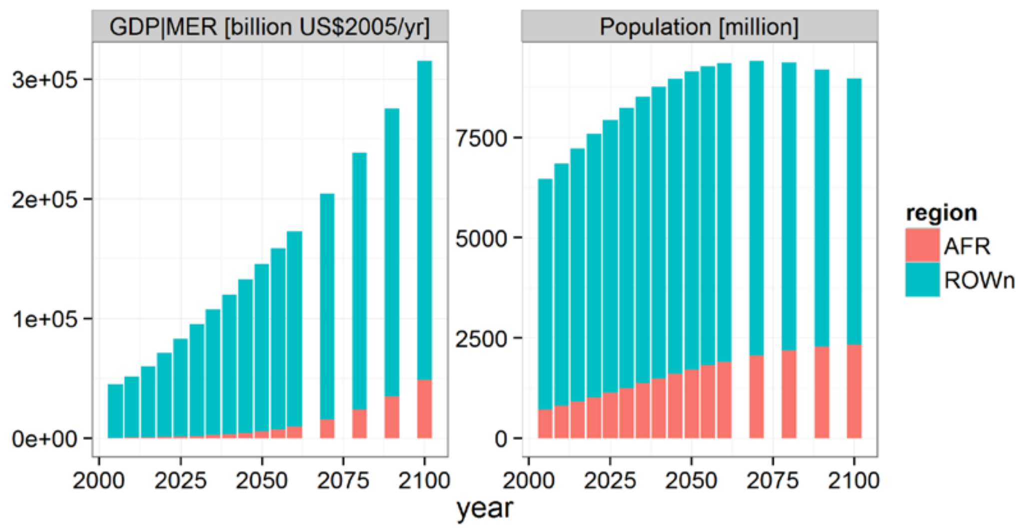

Fig.1: Global GDP and population scenario (AFR – Sub-Saharan Africa, ROWn – Rest of the World)

2.2 Scenario design and implementation

Incentives for developing countries to join climate agreements heavily depend on the development impacts of climate policies. The design of climate policies is therefore a crucial issue. We developed a set of scenarios that cover three major dimensions of climate policy regimes, all of which are expected to have a significant development and distributional impact:

(1) Level of targeted climate stabilization (i.e. ecological efficiency)

(2) Degree of international cooperation

(3) Burden sharing balance (fairness dimension).

Variation of the first dimension implies a different intensity of mitigation efforts and hence of mitigation costs. We do not quantify the benefits of climate stabilization (i.e. account for avoided climate change damages). Apart from a business as usual scenario, we consider climate policy scenarios that stabilize atmospheric greenhouse gas concentration at around 450 ppm and 550 ppm. This corresponds to a radiative forcing level of 2.6 W/m^2 and 3.7 W/m^2, respectively. Intermediate overshoot is allowed for the more stringent forcing target.

The cooperation dimension represents two different aspects – technology cooperation and policy cooperation. The assumption on technology cooperation determines whether international technology diffusion is actively supported or not. In a globally optimal world with full cooperation, represented by a Global Social Planner, external effects of investments in modern technologies are internalized and hence technology diffusion is supported. In a non-cooperative world, actors do not take these positive spillover effects on other regions into account. The second aspect relates to direct climate policy cooperation. In most scenarios, we assume that the different world regions behave cooperatively in achieving the long-term climate target (i.e. the GHG stabilization level). We consider two alternative climate policy instruments, emissions trading as well as a global carbon tax, in order to assure economic efficiency of the policy regime. However, in two stabilization scenarios we consider a fragmented climate policy regime characterized by different carbon tax levels in the different regions. In both scenarios, we assume that a global policy regime is enforced from 2040 onwards only. Nevertheless, the stabilization of atmospheric greenhouse gases at 450 ppm and 550 ppm CO2eq is still achieved until the end of the century.

The third dimension is about the allocation of emission permits and the underlying fairness. We consider three different allocation schemes. The first one represents an implicit allocation. Based on regionally equalized marginal costs of emission abatement, it implies no incentive of any region to trade emission permits but also no compensation for any mitigation effort. This allocation scheme is represented by a global tax scenario. Beyond that and with our focus on the perspectives of Sub-Saharan Africa we furthermore consider two alternatives that are related to the equal per capita allocation principle – per capita convergence, on the one hand, and allocation according to an intertemporal population share, on the other hand.

Table 1 provides an indication of the scenario names as used in the following and the associated characteristics of the three scenario dimensions. Note that the two aspects of the cooperation dimension are combined in a single representation.

Table 1: Scenario matrix

Climate target	**Cooperation**		**Allocation**		
			Equal marginal abatement costs	**Population share**	**Per capita convergence**
Baseline		BAU			
450 ppm	**Cooperative**		450TAX	450POP	450CC
550 ppm			550TAX	550POP	550CC
450 ppm	**Non-cooperative**		450SPA		
550 ppm			550SPA		

Implementation of the scenarios results in a number of model specifications which partly include substantial changes of the default implementation of REMIND. The first dimension on climate stabilization is technically just a parameter variation. Within the baseline scenarios (BAU), the welfare optimization is not subjected to a climate target and hence the energy conversion sector is not constraint by emission reduction needs. A forcing target of 2.6 W/m^2 and 3.7 W/m^2, represented by an upper bound for the respective model variable, is implemented for the 450 scenarios and 550 scenarios, respectively.

More significant changes relate to the dimension of cooperation. Whereas in the default model version, a social planner maximizes global welfare while internalizing existing externalities, in a decentralized model version, each region is represented by a representative household that maximizes regional welfare. The decentralized solution (Nash solution, market solution) deviates from the global Social Planner solution (Negishi solution) due to the existence of a non-internalized technological learning externality (for technical details see Leimbach et al., 2015). Technological learning is linked to the installation of capacities of modern energy conversion technologies. Investment costs for learning technologies decrease with each additional capacity independent of where it is build up. The social planner internalizes this externality, emulating a world with technological cooperation. The Nash solution, in contrast, simulates a world without such cooperation - even though technology diffusion still exists in the form of embodied and disembodied technological spillovers.

In addition to constrained technological cooperation, the non-cooperative scenarios also include limited climate policy cooperation. A set of scenarios (450SPA and 550SPA) is designed to simulate fragmented policy regimes that start with regionally different carbon taxes and enforce a cooperative policy regime with a global carbon tax not before 2040. Agreement on the implementation of the global policy regime is assumed to be taken in 2025. Furthermore it is assumed that there is a linear transformation from the regional carbon tax in 2025 to the globally unified carbon tax in 2040. Sub-Saharan Africa starts with a significantly lower carbon tax (1$/$tCO_2$ in 2020) compared to other regions (e.g. USA: 12$/$tCO_2$, China: 5$/tCO_2 in 2020) and also compared to the full cooperative scenario.

The allocation dimension is only analyzed within the fully cooperative model setting. A non-compensation scheme is contrasted with two burden sharing schemes. The former is implemented as a tax scenario, the latter as cap-and-trade scenarios. In both tax scenarios we assume an exponential tax path (increasing by 5% per year) that ensures either achieving 2.6 W/m^2 or 3.7 W/m^2 in 2100. Convergence towards the climate target is achieved by iteratively adjusting the initial tax according to the reaction of the climate system, without including the climate system as endogenous part of the optimization problem. This is different under the remaining realizations of the allocation dimension. A reduced-form climate model is part of the welfare optimization. As part of this optimization, a global emission trajectory is computed. The allocation scenarios differ according to the share of emission permits each region is distributed. The global budget of permits allocated in each period varies in accordance with the optimal global emission trajectory. While the "tax" allocation reproduces a permit allocation that yields a cost-efficient solution without any permit trade, both other allocation scenario sets include permit trading in order to achieve the efficient solution. The per capita convergence (C&C) regime starts with a permit allocation according to the status-quo (with the base year 2005), i.e. according to the regional emission shares in 2005, and shifts linearly to an equal per capita allocation of permits in 2050. The third allocation is novel and not yet used in integrated assessment studies. Like the

C&C scheme, this allocation scheme is based on an equal emissions per capita principle. It determines a fixed allocation share *S* of region *r* based on the cumulated population share over time horizon *t=1,…,T*:

$$S_r = \sum_t \frac{P_{r,t}}{\sum_r P_{r,t}}$$

Population values $P_{r,t}$ are derived from the SSP2 population scenario presented above.

By construction, this allocation scheme depends on an agreed population scenario, but not so much on its time profile. In particular, it prevents countries and regions to be indirectly penalized for high future population growth. Commonly, with the contraction of the global permit budget in mitigation scenarios future generations are allocated with a lower amount of permits per capita. This hits regions and countries with high population growth disproportionally. The proposed cumulated share scheme partly compensates this effect. It grants these regions a higher portion on the global budget in times when their population share is lower but the global permit budget is larger. In an analogous manner, it lowers the burden in scenarios where negative emissions have to be achieved in the long run. Compared to the C&C scheme, less negative emissions have to be provided by regions with growing population.

3. Development Impacts of Mitigation Policies

3.1. Mitigation costs in scenarios with varying stabilization and cooperation

Within this section we discuss the development impacts of mitigation policies by evaluating the economic cost of mitigation in Sub-Saharan Africa and the rest of the world. In section 4, we continue the discussion of development impacts by analyzing the transformation needs of Sub-Saharan Africa's energy system. The overall economic costs of climate change mitigation are represented by the discounted aggregated consumption losses of a mitigation scenario compared to the respective BAU scenario. According to a general pattern, differences in mitigation costs between regions are at least as significant as differences between scenarios. Scenario-independent variation of mitigation costs identifies structural differences of regions. Regions with a comparatively high income share of energy and with a high share on fossil fuel exports face higher mitigation costs than other regions.

Along the dimension of ecological efficiency, we see the largest differences (see figure 2). If all technologies are available and if cooperation is global, global mitigation costs can be contained. Based on the given economic growth scenario, they amount to around 0.4% for the 550TAX scenario and around 1.5% for the 450TAX scenario. All regions demonstrate higher mitigation costs with a more ambitious climate target. This cost increase is lowest for Latin America. As a major biomass exporter, this region benefits from an increasing biomass demand which is driven by an intensive use of energy conversion technologies based on biomass combined with carbon capture and sequestration (BECCS). Sub-Saharan Africa faces above-global-average mitigation costs which amount to 1.4% and 2.9% for the 550TAX and the 450TAX scenario, respectively.

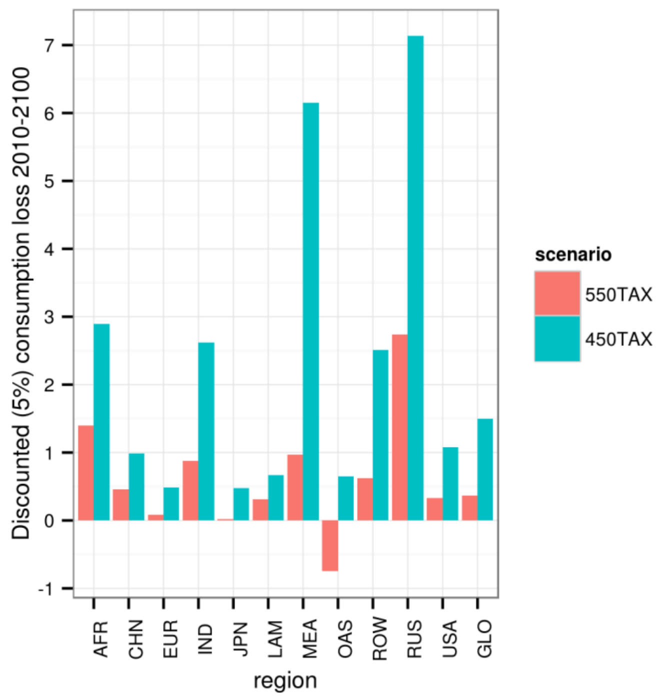

Fig. 2: Mitigation cost under scenarios with varying ecological efficiency (AFR – Sub-Saharan Africa, GLO – World)

Simulation results from scenarios with limited cooperation predominantly demonstrate additional consumption losses. The combined effect of limited technological and limited policy cooperation yield an increase of mitigation cost at the global level of around 0.04 and 0.2 percentage points for the 550 ppm scenario and the 450 ppm scenario, respectively (see figure 3). This is in line with other studies (e.g. Bertram et al., 2015). The isolated technology impact is comparatively small since knowledge spillovers exist independently of whether investors internalize this externality or not. Technology diffusion by knowledge spillovers from investments with non-internalized spillovers of this kind accounts for savings of mitigation costs in the order of 0.4 percentage points in the 450 ppm scenario.

With delayed cooperation in climate policies, there is a lock-in effect that becomes more costly when technological cooperation is weak. However, for some regions such a delay turns out to be beneficial, among others for Sub-Saharan Africa. Mitigation costs under a policy regime that starts with differentiated carbon taxes decline by 0.15 percentage points in the 550 ppm scenario and 0.5 percentage points in the 450 ppm scenario for this region. The long-term impact of the higher global carbon tax that has to be implemented to meet the agreed climate target when global cooperative action is delayed, is not only compensated by cost-savings in earlier periods due to a very low regional carbon tax, but also by increased revenues from biomass exports and decreased expenditures for oil imports. The increased demand on biomass in the non-cooperative scenario results from higher short-term levels of greenhouse gas emissions that will be compensated by an increased use of BECCS technologies in later periods.

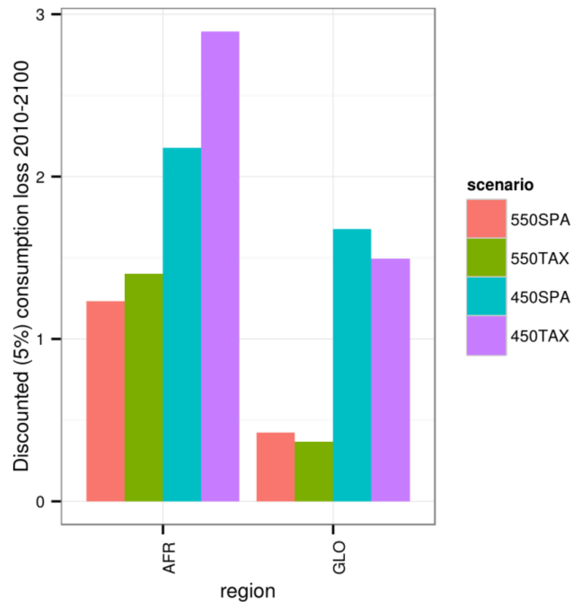

Fig. 3: Mitigation costs under scenarios with varying ecological efficiency and cooperation level (AFR – Sub-Saharan Africa, GLO – World)

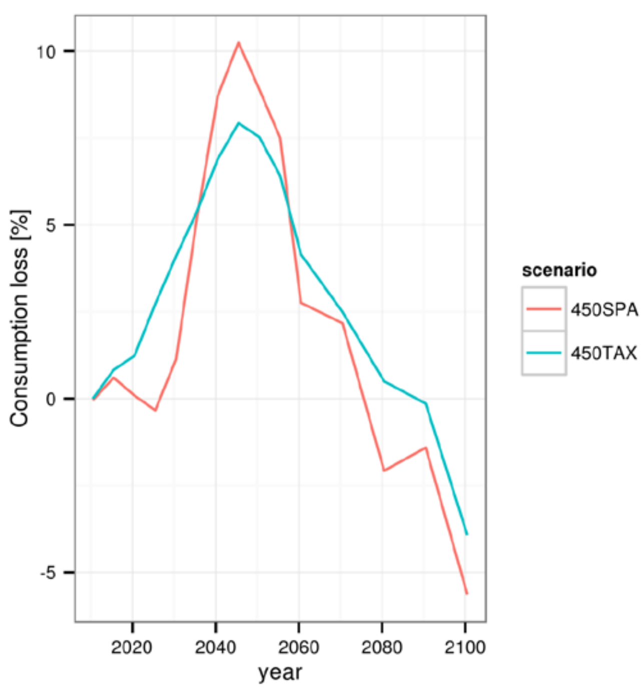

Fig. 4: Mitigation costs of Sub-Saharan Africa over time

While demonstrating lower aggregated mitigation costs, the non-cooperative scenario exhibits the more extreme intertemporal distribution of mitigation cots compared to the cooperative scenario (figure 4). The generation living between 2040 and 2060 is exposed to highest mitigation costs (between 3% and 10%), whereas the generation living before 2030 and after 2075 bear not at all any mitigation costs. The time profile of the cooperative scenario is qualitatively the same, but less extreme.

Regional mitigation costs have to be interpreted carefully. First, while for most regions they are higher in 450 ppm scenarios than in 550 ppm scenarios, the more ambitious climate targets are linked to lower climate change impacts, hence reduce potential economic losses due to unaccounted damages. Second, all tax scenarios considered so far assume a global tax without any transfer schemes. Given the differences in historic responsibility for climate change and in the capabilities to mitigate, such an assumption seems rather unrealistic. We therefore combine further analysis of mitigation costs with addressing the burden sharing issue and the development perspective of Sub-Saharan Africa.

3.2. Mitigation costs in scenarios with varying allocation

As the least developed world region, Sub-Saharan Africa is expected to be highly vulnerable to climate change impacts. In order to overcome poverty, Sub-Saharan Africa has to enter a period of sustained economic growth. As in other regions in the past and present, economic growth is fueled by energy use. Based on today's energy mix in developing regions, a substantial increase of GHG emissions can be expected to occur in Sub-Saharan Africa. This is in sharp conflict with the global interest of emission reduction in order to meet agreed climate targets.

Scenario results are now assessed against the background of Sub-Saharan Africa's legitimate demand for development. This is taken into account by addressing the dimension of allocation and burden sharing. The burden sharing dimension has no major global effect, i.e. the common feature of separability between efficiency and distribution holds in our model. From the scenarios we have analyzed so far, we can hardly conclude that Sub-Saharan Africa will support an immediate global climate policy based on a uniform carbon tax. Above-global-average mitigation costs are demonstrated in the 450TAX and 550TAX scenarios. The fragmented policy regimes 450SPA and 550SPA would ease the economic burden of Sub-Saharan Africa (see previous section), but it is inefficient from a global point of view. In order to maintain global efficiency and to provide incentives for the less developed world region, a cap-and-trade climate policy regime with initial permit allocation can be implemented. We analyze two implementations of such a regime (introduced in section 2) and contrast them with the global carbon tax regime. In order to avoid an interference with the ecological dimension in interpreting the results, we only compare scenarios with the same climate target.

From the simulation results it turns out that Sub-Saharan Africa is unequally affected by different allocation scenarios. In a number of scenarios, Sub-Saharan Africa even benefits from climate policy in addition to the avoided damages. This is in line with Table 1 in Mattoo and Subramanian (2012), which shows that Nigeria (as the African representative) benefits in the most important allocation schemes. Specifics of the policy regime, in particular the initial permit allocation in an international emissions trading system, have a major impact on Sub-Saharan Africa's mitigation cost (figure 5). It is not the per capita convergence scheme (450CC, 550CC) that favors Sub-Saharan Africa most. In contrast, regarding the 450 ppm case, there is only a small advantage compared to a global tax regime or an equivalent permit regime. The time when Sub-Saharan Africa can take full advantage of the approached equal per capita allocation of emission permits coincides with the period where the annual global emission budget declines quickly to zero and even below. The per capita convergence scheme is more favorable for Sub-Saharan Africa under the less stringent climate policy (550CC). Simulated mitigation costs of Sub-Saharan Africa amount to 2.1% and -0.5% under a per capita convergence scheme for a 450 ppm scenario and a 550 ppm scenario, respectively (see figure 5).

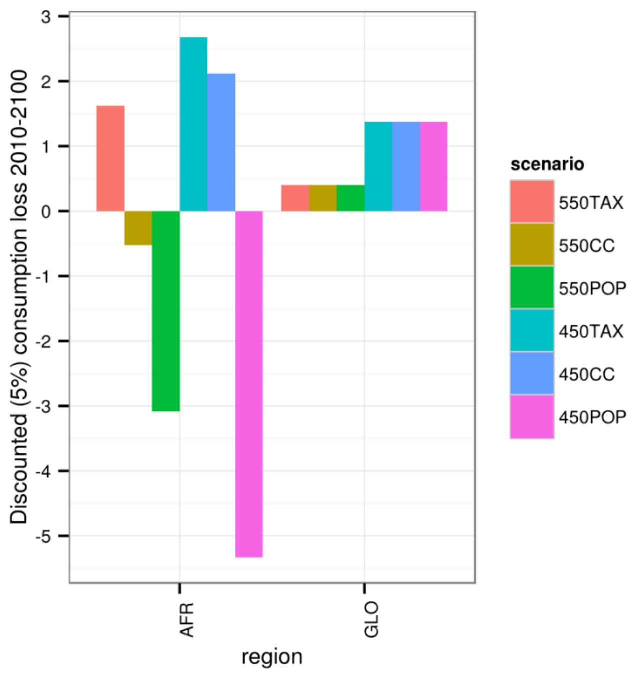

Fig. 5: Mitigation costs under scenarios with varying allocation rules (AFR – Sub-Saharan Africa, GLO – World)

A new allocation rule that takes the equity principle much better into account and reconciles the potentially opposite dynamics of the emission reduction paths and the demographic trajectory is the cumulated population share (450POP, 550POP). Sub-Saharan Africa could benefit a lot under such policy regimes (figure 5). Aggregated consumption losses shift into gains: almost -5.3% in the 450 ppm scenario and -3.1% under the 550 ppm scenario. For all other regions, as a whole, this implies an increase of mitigation costs in the order of 0.2 percentage points. Surprisingly, mitigation costs are lower in the 450 ppm scenario than in the 550 ppm scenario for Sub-Saharan Africa under this allocation regime. In order to provide good explanation we prepared a decomposition of the mitigation costs (figure 6). In the 450POP scenario, a GDP loss of around 5 % and higher energy system costs of around 4% are overcompensated by savings on investments (1%) and fossil imports (3%), combined with additional incomes from biomass export (3%) and permit export (7%). Both latter trade effects yield higher consumption gains in the 450POP scenario than in the 550POP scenario despite of higher GDP losses and energy system expenditures. The positive perspectives implied by this allocation scheme provide substantial incentives to Sub-Saharan Africa for supporting an international climate protocol.

The amount of revenues from permit and biomass trading includes huge financial transfers. Jakob et al. (2014) point out that large climate transfers might cause problems if administered poorly. Such a "climate finance curse" could be caused by high volatility of transfers due to large price changes for emission permits, a "Dutch disease" effect and rent-seeking and corruption. These effects could be avoided through a number of measures including improved (financial) institutions, adjusting macro policies or international involvement through the Green Climate Fund. Financial transfers thus have a great potential to render a climate agreement fair, but they must be administered with care.

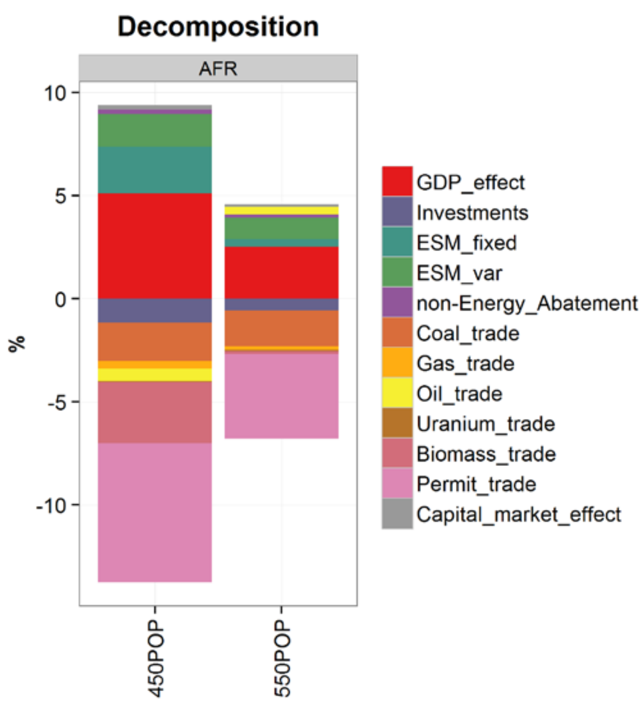

Fig. 6: Decomposition of mitigation costs

4. Transformation of the energy system

4.1 Transformation under full cooperation

Development impacts as discussed in the previous section are linked to a transformation of the global economy to manage a timely turnaround of the global emission trajectory as shown in figure 7. The climate target (dimension of ecological efficiency) predominantly defines the global emission trajectory and hence the mitigation gap that needs to be closed by this transformation. While continued fossil fuel consumption yields an increase of greenhouse gas emissions up to 87 $GtCO_2eq$ in the baseline scenario, they have to decline almost immediately from today's level in the 450TAX scenario or stabilize at around 55 $GtCO_2eq$ before declining in 2040 in the 550TAX scenario. In the long run, negative emissions (CO_2 removal from the atmosphere with technologies like BECCS) and emissions close to 0 $GtCO_2eq$ show up in the 450TAX scenario and the 550TAX scenario, respectively. By comparing the baseline scenario and first-best climate policy scenarios, we now want to assess the challenges regarding the energy system transformation and the additional investments needed when Sub-Saharan Africa joins a global coalition to mitigate climate change. As the allocation has no impact on this transformation, we focus on baseline and tax scenarios.

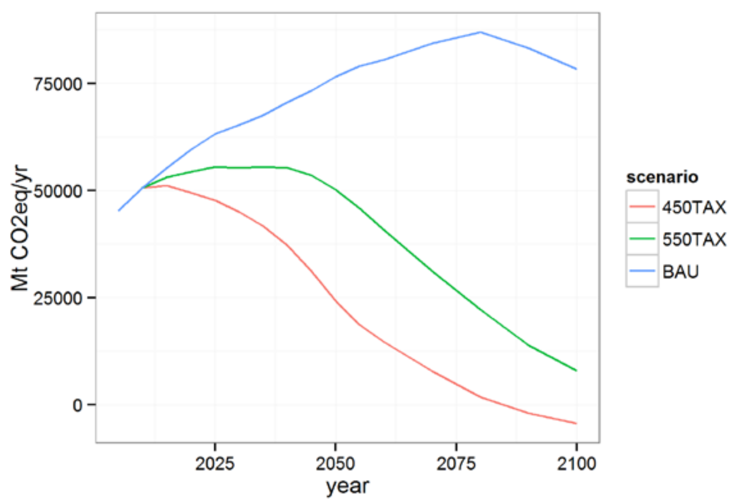

Fig. 7: Total GHG emissions in Mt CO_2 equivalent

According to our simulation results, Sub-Saharan Africa has the highest growth rates in energy demand (figure 8). Acceleration of economic growth in the early development stage is fueled by energy input. Under climate policy, Sub-Saharan Africa faces two challenges. Compared to the baseline scenario, energy consumption growth has to be reduced and a major transformation of the energy system has to be managed. The 450TAX (figure 8) and 550TAX scenarios are characterized by around 20% less final energy consumption in 2050 and beyond. Large efforts in increasing energy efficiency are needed. Moreover, while the baseline scenario demonstrates a slow shift from the use of final energy in form of solids (first traditional biomass, later coal) towards a balanced mix between liquids, gases and electricity, the policy scenarios request for a much faster increase of the electricity share. In the 450TAX scenario the electricity share is more than 30% in 2050 and more than 70% in 2100, while in the baseline scenario the share in 2100 is around 40%. The higher electricity share necessitates an increase of installed capacities by almost 10% per year over the next two decades, which is close to the 13% that Bazalian et al. (2012) mentioned as the figure that is needed in order to provide everyone in Sub-Saharan Africa with access to electricity.

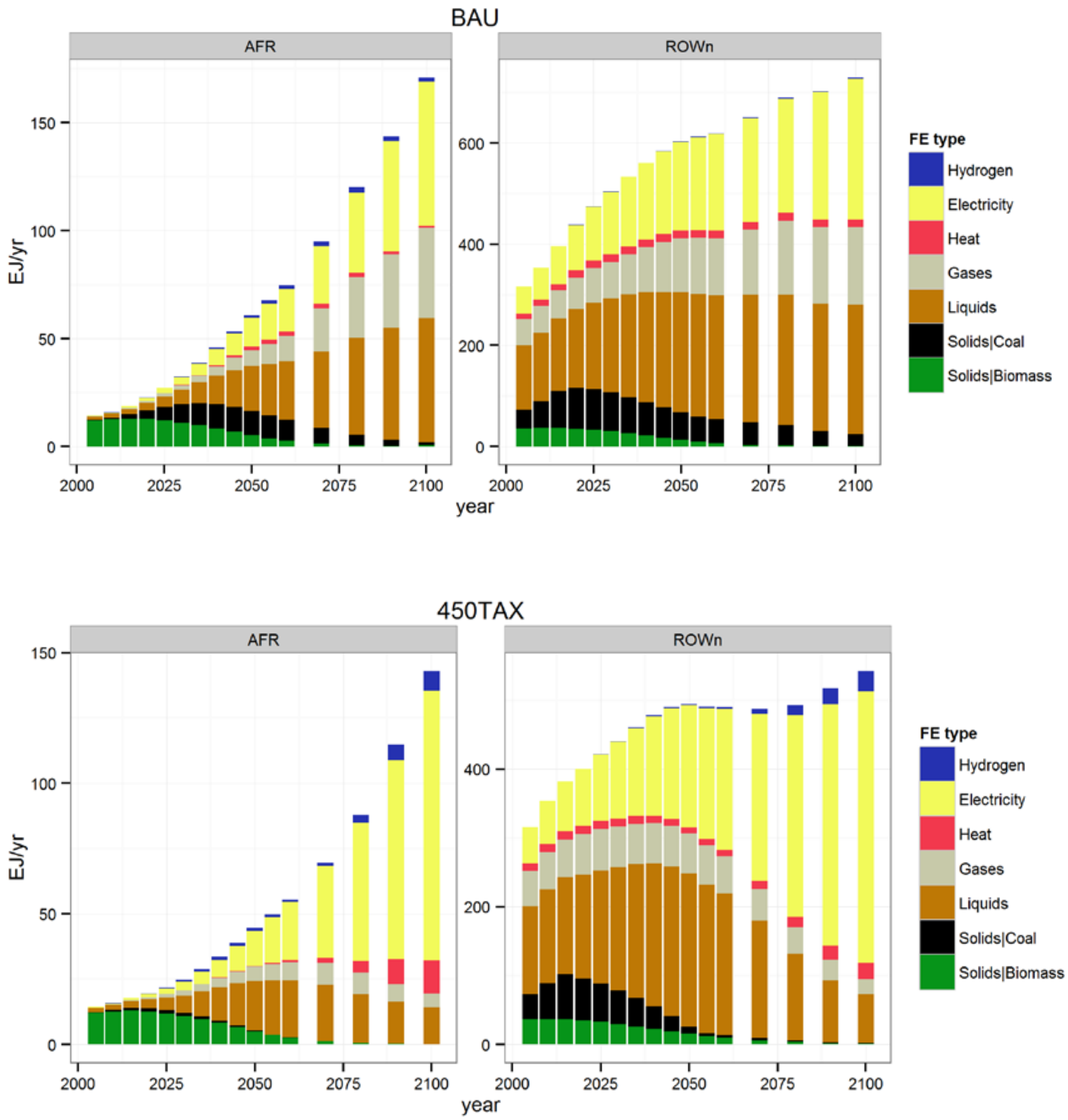

Fig. 8: Final energy demand of Sub-Saharan Africa and all other regions (ROWn) (upper panel: baseline scenario; lower panel: policy scenario)

Despite of increasing energy demand, final energy intensity is decreasing over time in all regions (figure 9). In the 450TAX scenario, the global average declines from 7.3 MJ/$US2005 to 2.3 MJ/$US2005. Sub-Saharan Africa gets close to the global average in 2100 starting from a final energy intensity of more than 30 MJ/$US2005 in 2005. Convergence of regional final energy intensity is less pronounced in relative terms. The ratio between the highest and lowest regional intensity decreases from around 10 to 5 between 2005 and 2100. Also final energy per capita converges across regions slowly (figure 9). It turns out that developing countries in Asia and Sub-Saharan Africa increase their per capita demand significantly, while having still a lower demand than the developed regions which either keep their current levels or as for the USA have to reduce them substantially.

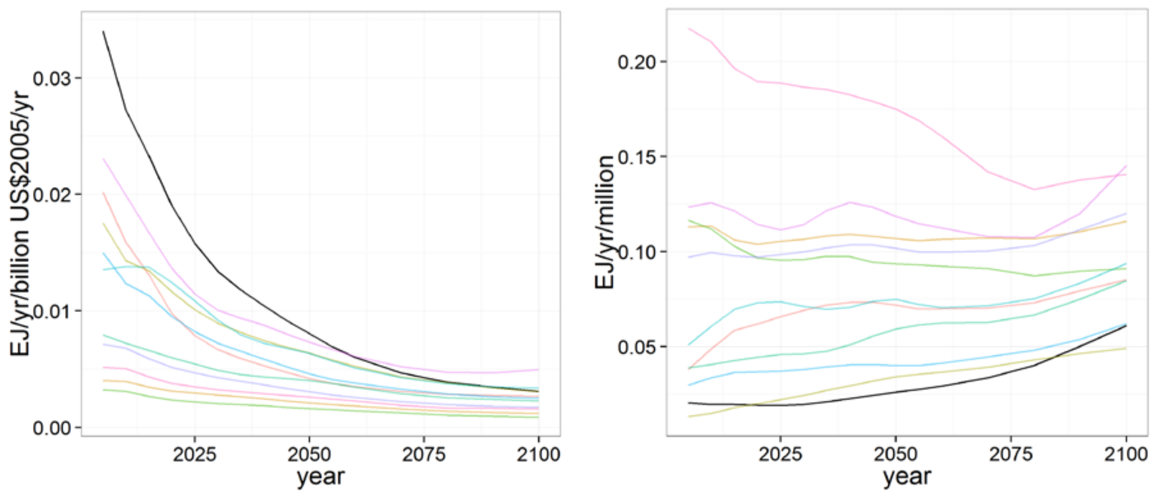

Fig. 9: Final energy intensity (left) and final energy demand per capita (right) in 450TAX scenario; the thick black line represents Sub-Saharan Africa

An increase of investments can be expected in order to achieve this fast transformation. In the climate policy scenarios, this transformation also includes a major shift from the use of conventional energy conversion technologies (e.g. coal power plants) to modern and more capital intensive renewable energy technologies (solar and wind). While the primary energy mix in both policy scenarios already demonstrates some divergence from the baseline energy mix in 2050, it is completely different in 2100 (figure 10). In the short-term, huge differences can be seen in energy investments. In the policy scenarios, use of coal is nearly completely phased out and use of gas is significantly reduced. Remaining coal and gas use in the 450TAX scenario is accompanied by CCS technology. Oil is used over the whole century (to a smaller extent in the 450TAX scenario than in the 550TAX scenario) since a complete decarbonization of the transport sector is much harder to achieve and is more costly than in other end use sectors.

Differences in the energy mixes between the 450 ppm and 550 ppm scenarios indicate different mitigation strategies. Energy efficiency improvements and CCS become much more relevant in the 450 scenario. CCS is in particular important in combination with the use of biomass which then allows for generating negative emissions.

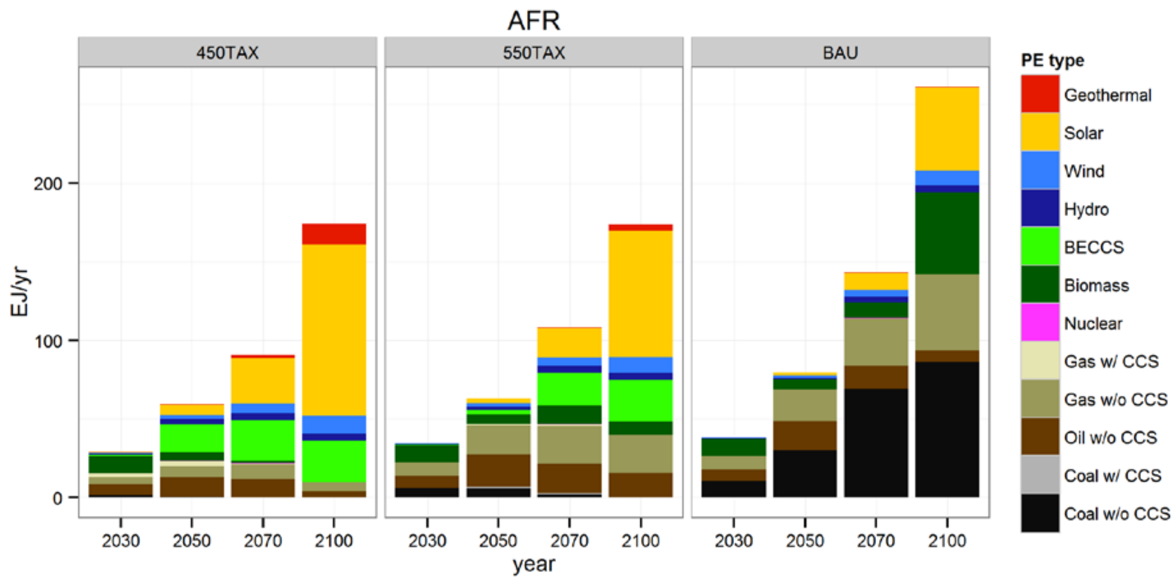

Fig. 10: Primary energy consumption of Sub-Saharan Africa

The optimal primary energy consumption path in Sub-Saharan Africa under ambitious climate policy can be summarized as follows: Until 2050, Sub-Saharan Africa expands its production of biomass massively. It then holds biomass production constant and expands renewable energy production. The projection thus hinges on the availability of the technology for biomass in the medium term and solar energy in the long term. While Sub-Saharan Africa is well endowed with natural capacities for biomass production and solar energy, it should be recalled that second-best conditions may make the implementation of this first best strategy difficult (Staub-Kaminski et al, 2014). One example could be the lack of a specialized workforce in Sub-Saharan Africa to produce energy in a more technology-intensive way.

4.2. Transformation under limited cooperation

Consideration of the dimension of cooperation yields different global mitigation strategies, though the impact is less significant than for the variation of the climate target. Technology diffusion is likely to help in transforming the global energy system. In scenarios without delay of global climate policy, i.e. with a global tax becoming effective in 2015, the missing anticipation of technological learning represents a deficit in cooperation that delays investments in renewable energies (in particular solar photovoltaic) by 5-10 years. The impact is comparatively small since knowledge spillovers exist independent of whether investors internalize this externality or not. Nevertheless, while Sub-Saharan Africa's share of solar technologies (photovoltaic and concentrated solar power) on electricity production in 2050 is only 25% in the non-cooperative scenario (450SPA), it increases to around 42% in the cooperative scenario (450TAX).

Furthermore, as for the 450 ppm scenarios, with delayed cooperation in climate policies, coal is used in the coming decades to a much larger extent. Its share on primary energy is still around 20% in 2030 in the non-cooperative scenario, while less than 5 % in the cooperative scenario. Primary energy consumption is also significantly higher in the time span around 2030: 33EJ in the non-cooperative and 29 EJ in the cooperative scenario. Delay of global cooperation requests for stronger emission reduction rates in Sub-Saharan Africa at the mid of the century compared to the full cooperative scenario.

4.3. Energy system investments

While the transformation patterns are quite different for the different climate targets, with a given climate target these patterns are robust. Most regions follow the global pattern, shifting from fossil dominated energy supply to renewable dominated energy supply in the long run. Sub-Saharan Africa demonstrates above average use of biomass and solar, respectively. Immediate climate policy can provide additional advantage for Sub-Saharan Africa. Regions which invest strongly in one type of energy generation become locked into it to some extent. Power plants using coal for example are very long-lived. An early investment into coal would thus make it very expensive to switch to less carbon intensive forms of energy generation since the early retirement of power plants would reduce their overall profitability. For Sub-Saharan Africa, which yet has to build up power generation capacities (see figure 8), climate policy could avoid a lock-in into carbon intensive technology.

The left panel of figure 11 shows the challenge of transformation for Sub-Saharan Africa. Energy system investments in 2100 in the 450TAX scenario exceed the baseline investments by more than 30%. This results in an increase of the energy investment share on GDP from around 6% today to around 10% over the next three decades. This is in contrast to most other regions where at average this share is lower than 5% today and declining. Around one third of Sub-Saharan Africa's energy investments in the second half of the century will be directed into the installation of solar power plants. Purposeful use of international transfers and domestic energy policies have to carefully support this investment process. Moreover, given the high and in the mid-term increasing expenditures for energy system build-up, an institutional setting is required to ensure that energy prices will not be a too high burden for poor households. As there are further implications of the related transformation process that cannot be covered by the used model, we want to supplement our model analysis with an ex-post distributional analysis.

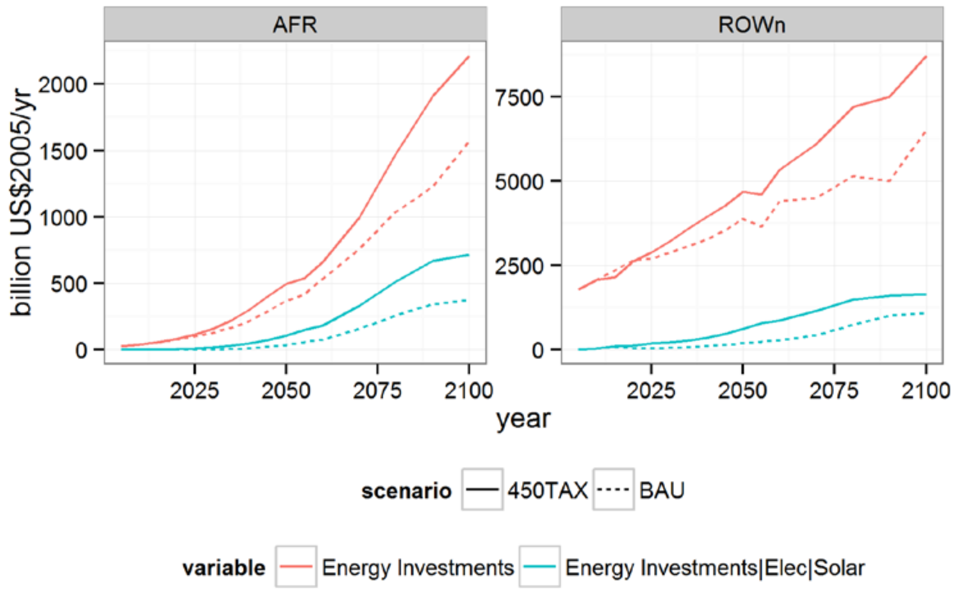

Fig. 11: Energy system investments (baseline scenario and 450 ppm scenario)

4.4. Distributional effects of climate change mitigation within Sub-Saharan Africa

While REMIND is well suited to analyze distributional effects of climate change mitigation between regions, some conclusions can be drawn on the distributional effects within regions as well. Again we focus on Sub-Saharan Africa. A high share of the African population currently lives on incomes below the poverty line and a high fraction of expenses in poor households is used for energy. Kaygusuz (2011) states that "The International Energy Agency (IEA) expects that the number of people depending on biomass for cooking will rise to around 2.7 billion in 2020, from 2.5 billion today". Most of these people will likely live in Africa. Hailu (2012) finds that in 2011 585 million (30.5%) Africans had no access to electricity. Rising energy prices could worsen poverty and increase inequality, since people without access to electricity have to purchase liquid and solid fuels that are likely subject to higher price increases (see below). They would thus be disproportionally affected by rising energy prices (Jakob and Steckel, 2013).

Higher energy prices due to climate policy might thus reduce the remaining income of the poor even more and cause energy poverty for this large part of the population. This can be illustrated with a simple identity,

$$I - pE = C \qquad (1).$$

Here I is the income of a certain income group, E is subsistence-level energy consumption as defined in Barnes et al. (2011) for example, p is the price for energy and C is remaining consumption (including energy consumption above subsistence level).

In order to determine the long run development of the remaining consumption we can represent income as

$$I = \varphi Y \qquad (2).$$

φ is the income share of a particular income group, in our case the bottom 10% for example will be of particular interest. Y is total economic output. The growth rate of the remaining consumption is thus given by

$$\frac{\dot{C}}{C} = \dot{\varphi}\frac{Y}{C} + \dot{Y}\frac{\varphi}{C} - \dot{p}\frac{E}{C} - \dot{E}\frac{p}{C} \qquad (3).$$

It follows that this growth rate will be positive if and only if

$$\frac{\dot{\varphi}}{\varphi} + \frac{\dot{Y}}{Y} > \left(\frac{\dot{p}}{p} + \frac{\dot{E}}{E}\right)\frac{pE}{C+pE} \qquad (4).$$

We can thus study the effect of climate change mitigation on non-energy consumption by going through the parts of this inequality.

The amount of subsistence level energy consumption, E, seems to be constant over time. Barnes et al. (2011) point out that the minimum requirement may depend on culture, which determines cooking habits, and region, which determines heating requirements, but does not mention dependence on time. Krugmann and Goldemberg (1983) do not consider time variance either. We thus assume E to be time invariant.

The share of income received by the poorest households φ might change for two reasons. One reason is the natural evolution of inequality. Deininger and Squire (1996), Table 5, see the Gini coefficient in Africa fluctuating between 43 and 50 (on a scale from 0 to 100) between the 1960s and the 1990s. Alvaredo and Gasparini (2013), Figure 4.6, plot the African Gini coefficient at 45 between 1990 and 2008. We therefore assume that inequality within Africa is roughly stable over time. The second reason why the share of income for the poorest households may rise could be pro-poor redistribution by the government. In order to identify potential adverse consequences of climate policy, we assume that governments do not engage actively in reducing inequality and thus keep φ constant.

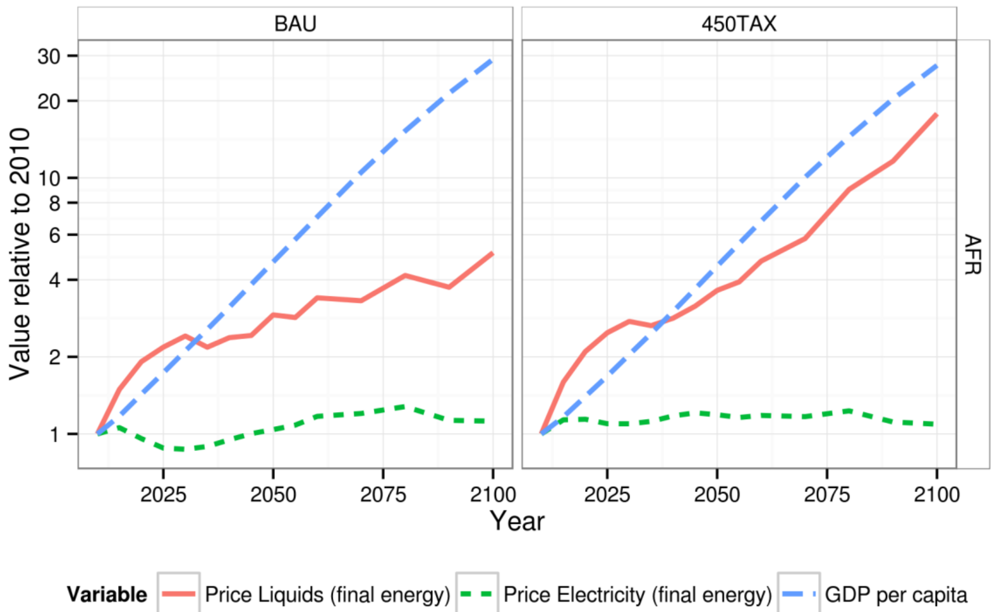

Fig.12: Time series of the growth in income per capita, prices for liquids, and the electricity price in the baseline and 450TAX scenario (variables are normalized to their values in 2010, and shown on a logarithmic scale)

If E and φ are constant and C is small, inequality (4) shows that the sign of the growth rate of non-energy consumption depends strongly on the relative size of the growth rate in output Y and the energy price p. Figure 12 shows the level of per capita income and final energy prices in REMIND compared to the base year 2010. The development of these variables in the business-as-usual scenario is contrasted to those in a scenario with ambitious climate policy. Climate policy causes the price for liquid energy to rise much faster in the policy case. Electricity generation, however, can be decarbonized, so that electricity prices grow much more slowly than prices for liquid energy in all scenarios.

The low rate of electrification in Africa cited above implies that the poorest households currently strongly rely on liquid fuels. If this dependence persists, the simulation results indicate that they will see a declining share of non-energy consumption until 2030. Climate policy would in addition strongly reduce the scope to increase it until the year 2100. In the business-as-usual scenario, price of liquid fuels would increase five-fold. The price for liquid fuels grows by a factor of 18 in the climate policy scenario. Significant parts of additional income would have to be used in order to compensate this price increase. If the dependency on liquid fuels would continue it could be argued that climate policy puts a severe burden on the poorest households.

Some kind of active redistribution policy would thus be needed to allow the poorest income group to benefit from growing GDP. One option is to increase their share φ of income so that they can consume more in spite of the higher expenses for liquid fuels. A much more promising option, which is line with the high electricity share in the model results (see figure 8), would be to expand the electricity grid. In this way, ambitious climate policy, which entails a strong shift from fossil fuels to renewables and rapid electrification, will provide the poorest part of the population with access to a cleaner and more versatile kind of energy. Prices of electricity are expected to show a low rate of increase. According to model results, the price of electricity rises only by about 10% until 2100 in the case of cooperative climate policy (figure 12). Electrification and grid expansion is in line with previous proposals in the literature (Casillas and Kammen, 2010). There would thus be a strong synergy effect between poverty eradication and climate change mitigation.

5. Conclusions

Climate stabilization needs contributions of developing regions to global greenhouse gas emission reduction. These contributions will only happen if they do not significantly interfere with the legitimate development needs of poor countries. This study characterizes a climate policy regime that prevents Sub-Saharan Africa from being affected by major economic costs when joining the global coalition that takes the necessary actions to achieve climate stabilization. The incentives of joining a global agreement can clearly be increased with a climate policy regime that includes a cap-and-trade system with an equity-based burden sharing. This would also make it easier for Sub-Saharan Africa to support early and cooperative action. Moreover, technology and policy cooperation help Sub-Saharan Africa and all participating actors to contain the cost of climate stabilization.

This study estimated economic costs of climate change mitigation based on simulations with the IA model REMIND. Simulations yield mitigation costs for Sub-Saharan Africa in the range between -5% and 3%. But even with consumption gains, substantial challenges in transforming the energy system and in building up institutional capacities are implied. Final energy intensity has to be reduced by 90% over the century. The use of fossil energies has to be faded out until 2050 or be combined with CCS technologies, and the electricity share has to be tripled. Compared to the baseline scenario additional energy system investments increase by 30% until 2100.

Major challenges are also associated with the substantial transfer (or revenues from the carbon market) in climate policy scenarios. The positive balance for the development perspectives will only hold if the financial means will be applied in a socially efficient way. This includes investment into new energy conversion technologies, but also support for poor households which temporary may be confronted with a decline in non-energy consumption due to increasing energy prices.

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