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Greening Africa? Technologies, endowments and the latecomer effect ☆

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ABSTRACT

Africa is well endowed with potential for hydro and solar power, but its other endowments – shortages of capital, skills, and governance capacity – make most of the green options relatively expensive, while its abundance of hydro-carbons makes fossil fuels relatively cheap. Current power shortages make expansion of power capacity a priority. Africa's endowments, and the consequent scarcities and relative prices, are not immutable and can be changed to bring opportunity costs in Africa closer to those in the rest of the world. The international community can support by increasing Africa's supply of the scarce factors of capital, skills, and governance.

1. Introduction

Africa is currently the green continent: its average CO_2 emissions per person are less than one tonne pa, one-fifteenth of Europeans and one-thirtieth of North Americans.[1] With 12 percent of the world population, Africa accounts for just 2.4 percent of world emissions. However, this is a consequence of Africa's poverty. Already, emissions intensity in Africa (per unit GDP at PPP) is at the world average; the continent's 2.4 percent of world emissions is generated by just 2.4 percent of world income. Fig. 1 illustrates the time path of emissions intensity for selected countries, including an average of Tanzania, Kenya, Uganda and Nigeria ('Four African countries') and separately for South Africa. South Africa has one of the highest emissions intensities in the world, linked to its endowment of coal[2]; the four others have emissions intensity higher than that of the UK and similar European countries. After decades of stagnation, the Africa region is now growing quite rapidly; indeed, in the medium term growth is likely to accelerate as many opportunities for convergence are realised. Globally, development typically generates an inverse-U pattern of emissions intensity per unit of income with its peak between \$2000 and \$3000 per capita (Stefanski, 2010). An implication is that Africa's emissions will rise due both to rising income and increasing emissions intensity.

Emissions are a global public bad which will affect regions differentially. Much of Africa will be adversely affected because its heavy dependence upon rain-fed agriculture exposes it to the hotter and more volatile conditions generated by climate change. Thus, Africa has a particularly strong interest in the development of a robust global system of mitigation. However, the costs of mitigation vary across regions, and it is these costs that will most powerfully influence the choices made in Africa in the coming decades. Conceptually, 'greening' development is about the introduction of both new constraints and new opportunities. If the only change is to require that development emits less CO_2 than would otherwise be the case, then a new constraint is binding and more rapid greening would reduce Africa's growth. However, greening in the rest of the world will induce the development of new mitigation technologies both for energy generation and energy use, some of which may be particularly suited to African conditions.[3] How fast should Africa adopt mitigation measures, given its particular characteristics and the technologies available?

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[1] Sub-Saharan Africa excluding South Africa. World Development Indicators and BP (2011). For the remainder of the paper Africa will be taken to mean the whole of Sub-Saharan Africa.

[2] And accentuated by energy security concerns during the apartheid era.

[3] IPCC (2012) provides an extensive overview of renewable technologies, and chapter 9 addresses related sustainable development issues.

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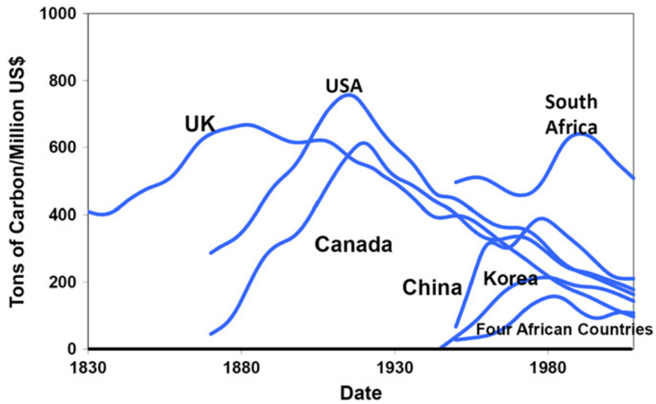

Fig. 1. Emissions intensity through time.

Choices made in Africa will (and should) be shaped by the local costs of alternatives. These local costs differ from those in high income countries because of the distinctive features of Africa, of which four are most relevant. The first is Africa's *natural endowment*. Africa has natural advantage in hydrocarbons (12.2 percent of world oil production and 9.5 percent of proven reserves, plus significant quantities of coal and gas).[4] It has hydro-electric potential, producing 2.7 percent of world hydro-electricity but with an estimated 8 percent of world potential.[5] It has sunlight, more intense and more evenly spread throughout the year than in the Northern regions.[6] And it is well endowed with land, this including tropical rain forest with implications for carbon sequestration, and under-utilised arable land with potential for bio-fuels. Hence, Africa's natural endowment is already energy-abundant and prospective innovations in green technology will make it more so.

However, utilisation of these natural assets requires other inputs, in which Africa is scarce. One is the *capital endowment*, meaning the accumulated stocks of physical capital and levels of human capital and skills. Africa is scarce in stocks of these forms of capital, and also has low savings rates and poorly developed financial markets.[7] Funds to undertake capital investments – by either the public or private sector – are therefore expensive. Another is *governance endowment*, meaning the institutional and governance capacity required to implement and regulate economic activity. This is partly lack of capacity, but also involves a set of political economy obstacles which preclude some policies, and which have been particularly acute in the energy sector. A critical consequence of Africa's distinctive capital and governance endowments is that it has not been able to harness its natural endowment: despite its natural energy-abundance, the region is chronically short of energy, with firms and households facing acute shortages of power.

The fourth distinctive feature follows from these; Africa is a *latecomer*. Developed regions of the world have sunk capital in irreversible investments in their power supply, transport networks and urban structures. Africa has yet to do so and therefore has a potential latecomer advantage. New technologies will be available at the time when Africa is making these investments, offering a potential for investments that are more efficient in a number of dimensions, including emissions intensity. However, as a latecomer currently suffering energy shortages, Africa also needs to make these investments soon and not delay in anticipation of further technological change.

[4] BP (2011). Excluding the Middle East, the numbers are 21% and 17% respectively.

[5] Intergovernmental Panel on Climate Change (IPCC), 2012.

[6] Deichmann et al. (2011) report estimates that total renewable energy potential in Africa is 10–12 times current energy consumption levels.

[7] Savings rates of around 17 percent of GDP compared to 31 percent on average for middle income countries.

The extent to which Africa adopts green technologies will depend on the interaction between these features of Africa's endowment and the characteristics of the technologies that are available. Some green technologies may be particularly low cost in Africa, offering choices that are green and economically efficient. However, it seems likely that many others may be particularly high cost because they use more of things in which Africa is scarce, and less of things in which it is abundant. The uptake of new technologies can only be understood in terms of their interaction with the region's endowments. Energy production of all sorts, and in particular much green energy, is an intensive user of capital, of regulatory and governance capacity, and of highly skilled labour. Since Africa is poorly endowed with these resources, diverting them into climate mitigation rather than other productive uses has high opportunity cost. Furthermore, Africa's abundant endowment of energy resources (oil, and also gas and coal) tends to reduce the local cost of using these fuels; this will lead Africa to base much of its energy production on fossil fuels. Africa's overall shortage of energy, in particular electric power, means that its marginal social value is therefore high, and expanding energy use is a priority.

These arguments are developed further in the remainder of the paper. In the next section we look at the implications of Africa's endowments for energy production, in particular power generation. Section 3 looks at energy use and Section 4 discusses the latecomer effect. The final section looks at broader policy options. Africa's endowments and institutions are not immutable, and local capacities and costs can be changed. Both international assistance and greater integration with the rest of the world economy may enable the region to bridge the gap between the local and international costs of mitigation and move to more rapid implementation of green technologies.

2. Energy generation: Natural advantage versus economic disadvantage

Africa has a substantial natural advantage in energy resources, both carbon-based and green. However, the conversion of natural energy resources into power is an economic activity in which Africa is at a comparative disadvantage because the conversion is intensive in governance, capital, and skill. In this section we draw out the interactions and the complementarities between various aspects of Africa's endowment and alternative technologies for energy generation.

2.1. Governance and political economy

Government has an unavoidable role in the generation of power, and in Africa this role is wider than in most other regions. Government involvement stems from scale economies in generation and the need for a grid, these large scale technologies forming a classic network industry. Under these conditions private provision tends rapidly to monopoly unless regulated. Historically, the most common solution to this problem has been to place power generation in the public sector, and this was the system inherited in Africa from colonial times. The severe capacity and political economy difficulties faced by African governments have made this approach dysfunctional resulting in under-investment, lack of maintenance, and severe and persistent power shortages.

The political economy of African energy policies can be conceptualised as two games, one played between the government and citizens, and the other between government and investors. The game between government and citizens concerns the pricing of energy. African governments are distinctive in that urban electorates hold them responsible for this price. The origins of this exaggerated responsibility stem from public ownership of energy generation and distribution, compounded by policies of generalised price controls which lingered in Africa long after they had been abandoned elsewhere. Africa's recent wave of democratisation has compounded

Table 1
Costs of electricity generation.

	Nuclear	Gas (CCGT)	Coal (US/USC)	Coal-China (Black SC)	Onshore wind	Solar PV	Large hydro-Brazil	Large hydro-China
Capital cost ($/kW)[1]	4102	1069	2133	602	2349	6006	1356	1583
O&M ($/MWh)	14.7	4.5	6.0	1.61	21.9	30.0	2.4	9.8
Fuel ($/MWh)	9.3	61.1	18.2	23.06	0	0	0	0
CO_2 ($/MWh)	0	10.5	24.0	n.a.	0	0	0	0
Expected lifetime	60	30	40	40	25	25	80	80
LCOE ($/MWh): 5%	58.5	85.8	65.2	29.4	96.7	410.8	18.7	29.1
LCOE ($/MWh): 10%	98.7	92.1	80.0	33.3[2]	137.2	616.6	34.0	51.5

LCOE = levelised cost of energy. CCGT = combined cycle turbines; US = ultra-supercritical.
Source: International Energy Agency (2010); Table 5.1, median country, columns 1–3, 5, 6: Table 3.7 columns 4, 7, 8.
[1] Overnight costs.
[2] Not including imputed CO_2 cost.

this problem, making governments wary of price decontrol. A spectacular illustration of these popular expectations was the national strike that paralysed Nigeria in January 2012 following removal of the government fuel subsidy.

The chronic shortage of generating capacity is in part a consequence of this under-pricing. Investment, whether public or private, is unviable unless prices are substantially increased. So severe are power outages that almost all citizens would benefit from the switch to higher prices and expanded supply. However, such a policy package has inevitably to be sequenced: prices must be increased before investment can be committed. This gives rise to a time-consistency problem. The coordination of citizen protest is costly and such protest will not be ended by promises of subsequent change: protest is now or never (Acemoglu and Robinson, 2000). Hence, citizens will only refrain from protest if the government provides a credible commitment to change. Following years of poor governance and inflated promises, African governments face acute credibility problems with citizens; they have no way of credibly assuring citizens that a price increase will indeed be followed by supply increases. This time-consistency dilemma also plays out within government in the divergent interests of Ministers of Energy and Ministers of Finance. The former wants to avoid the political opprobrium of raising the price of electricity, while being seen as the person responsible for increasing supply. The Minister of Finance wants to save costs of fuel subsidies and of capital expenditures. The Minister of Energy cannot credibly commit to the Minister of Finance that if he were to sanction an expansion in generating capacity, it would be followed by a price increase. Hence, the equilibrium is a stalemate in which price stays low and supply is rationed.

Government failure suggests that African power generation might be more effectively undertaken by regulated, possibly foreign-owned, private enterprises. However, regulation can never be fully specified in contracts: incomplete contracting is an irreducible feature of uncertainty. Investors might reasonably fear both corruption and bias against a foreign private company that replaced a public utility. In effect, the same government failure that precludes efficient public provision of power precludes the provision of credible regulation. The power of government to regulate, and the political pressure on government to intervene in pricing, also create the risk hold-up; once the investment has been made the investor is hostage to government decisions. These political impediments have played out in the actual experience of private sector involvement with electricity generation in Africa. The region has far less private participation than other regions, Eberhard et al. (2011) in their review of the sector summarise as follows: 'Power sector reforms originally followed the prescription of industry unbundling, privatisation, and competition, but electricity markets that meet these criteria are nowhere to be found in Africa (p79). They also note that the independent regulatory agencies often established as part of this reformist agenda are now widely seen as an additional source of political risk. Very few countries have significant generation by enterprises with private majority ownership, and two such privatisations have been reversed (in Senegal and Mali). While management contracts are somewhat more common, some of these have also been allowed to lapse (as in Tanzania).

What are the implications of these arguments for future energy choices? In broad terms they militate against investments that are large scale and have high capital costs. Evidently, the time-consistency problem is more acute the higher is the ratio of sunk capital cost (in generation or in a grid) to recurrent cost. The following sections suggest how particular technologies will be affected.

2.2. Capital and skill scarcity

Africa is capital-scarce: the implied high shadow price of capital is pervasive across households, firms and governments. African households are poor and so have very low savings. African governments lack the resources to finance major energy investments. Not only is the underlying household sector poor, but governments have not built effective tax systems and so their revenue base is inadequate for capital investment. Internationally, African governments rely upon aid, but this is likely to become more limited due to the chronic fiscal problems of the OECD. Their access to international private finance is expensive, and limited following the region's recent history of default and debt forgiveness. Natural resource revenues provide substantial funds for a few countries, but historically these revenues have largely been used for current consumption rather than investment. This leaves foreign direct investment (FDI) for private commercial power generation as the remaining possibility for financing African power generation; however this is deterred by political risk in long-lived investment projects as discussed above.

Power generation is generally capital intensive: intensity varies widely across technologies and data is given in Table 1.[8] While the table does not report all relevant costs (in particular capital costs associated with a power grid or with gas pipelines) the facts are clear. All generation is capital intensive, with gas, hydro and coal the least capital intensive and nuclear and solar PV the most. At a 5 percent discount rate and including imputed carbon cost at $30 per tonne of CO_2, onshore wind and solar are the two most expensive technologies. At 10 percent, the cost disadvantage of wind and solar widens further, illustrating the high cost of deploying these technologies in Africa. Hydro has substantial capital costs, but its long life and low operating costs make it amongst the cheapest.

As well as being capital intensive, the energy sector is also intensive in highly-skilled labour. Africa is the most skill-scarce region: the continuing shortage of power generation implies that there has been little on-the-job training; the region's tertiary education sector

[8] We use data from International Energy Agency (2010) which permits comparison of renewable and conventional technologies. There is a wide dispersion of costs across countries and technologies, and comparison should be treated with care. Detailed estimates of costs of renewable are contained in IPCC (2012).

is tiny and of low-quality; and the region haemorrhages its limited skilled workforce to other regions which, due to higher private incomes and more abundant public goods, offer skilled immigrants a far higher quality of life.

2.3. Hydro-carbon abundance

Africa's abundance of hydro-carbons is such that around two-thirds of oil production is exported from the continent, and fuels account for more than half of Africa's exports (IMF, 2007). During the coming decade this dependence upon carbon-based energy exports is likely to increase substantially. Historically, investment in prospecting has been heavily concentrated in the OECD: as of 2007 the stock of oil investment per square mile was around ten times larger in the OECD than in developing countries (Ross, 2011, Table 1.1). Within the latter, Africa has been particularly marked by under-investment. By virtue of this past neglect Africa has become the frontier for discovery. Since 2004 there have been oil and gas discoveries in Chad, Ghana, Guinea, Guinea-Bissau, Kenya, Liberia, Mali, Mauritania, Mozambique, Sao Tome Principe, Senegal, Sierra Leone, Tanzania, Togo and Uganda.[9] There are also substantial coal deposits, particularly in South Africa but now also including large fields in Mozambique.[10]

While a large quantity of these reserves is exported, their local abundance means that local energy use, for example in power generation, is fossil fuel intensive. If natural resources are *perfectly* freely traded, then exporters will get the full world price for their exports, and the local price of the resource will be the same as the international price. But there are a number of trade frictions that reduce the returns to exporting, driving the local price of the resource below the world price. Hydro-carbon abundance therefore makes it efficient for many African countries to choose power generation techniques which are emissions intensive.

The first trade friction that drives down the local price is that the region has exceptionally high costs of international transport.[11] Transport costs are incurred both on the energy exported and on the imports which energy exports finance. Hence, the opportunity cost of using energy resources domestically is the world price of energy, minus two sets of transport costs. This can justify a shadow price of domestic energy resources substantially below the prevailing world price. The high costs of transport matter most for those African countries that are landlocked, and some of the new deposits are in just such countries. For example, oil found in Northern Uganda is hard to export to world markets so it might appropriately be used locally to generate electricity, even though oil has been largely abandoned as a fuel for base load power generation in the rest of the world. The argument applies not just to landlocked economies, and is illustrated by the costs of coal-based electricity generation in different parts of the world. Heptonstall (2007) finds that the highest cost countries are those without coal (Japan, Sweden, Italy, in the range $60–$80 per MWh), the world average is around $50, while coal which is abundant in Australia and South Africa has respective costs of $36 and $27 per MWh (and see Table 1 for comparison).

The second factor that reduces the value of exporting is the volatility of commodity prices. If a resource rich country exports the resource, then it exposes itself to economically damaging volatility of its export earnings (van der Ploeg and Poelhekke, 2009). Domestic use reduces this exposure so is a form of insurance. Finally, if the country has some monopoly power in the resource – or is a member of a cartel such as OPEC – then the marginal return to exports is less than the price, once again encouraging countries to restrict exports while using the resource domestically. For example, Nigeria is a member of OPEC and so may find its exports of oil limited by its undertakings. For Nigeria to have sufficient refining capacity to meet domestic demand from its own oil resources (which is not currently the case), the domestic shadow price of oil should be set significantly below the world price.

These arguments point to local use of hydro-carbons, although it has not always been done effectively because of governance and regulatory problems. A greening of hydro-carbon use and production would be a reduction in the flaring of gas. In Nigeria around 70% of the gas produced as a by-product of oil extraction has been flared, accounting for nearly one-quarter of world gas flaring (Gervet, 2007). In Ghana, which discovered oil in 2007, the gas by-product will also be flared. There are two alternatives to gas flaring. One is to burn the gas domestically to generate electricity, this encountering the regulatory problems discussed above. The other is to convert the gas into LNG. While this makes the energy exportable and so avoids the domestic regulatory problems, it requires a major fixed investment and is only suitable at large scale. Even then it exposes the investor to potential hold-up if a future government requires some LNG to be sold domestically at a regulated price.

These arguments all point to the cost advantage of using local fossil fuels intensively. In Southern Africa this means coal, and in other regions more likely oil. Natural gas will also become much more important, both because of possible reductions in flaring, and also because of new gas finds off Mozambique and Tanzania.

2.4. Solar abundance

Superficially, the most promising new green energy technology for Africa is solar power.[12] It fits Africa's natural endowment of strong sunlight distributed evenly throughout the year. It does not need a grid, and so offers the prospect of a leapfrog technology comparable to mobile phones which swept across Africa because of the inadequacies of the region's landline networks. However, solar power is currently very capital intensive (Table 1). The small enterprises that characterise most of the African private sector and might be expected to use this technology face an extremely high implicit discount rate. For example, a study of small enterprises in Ghana (Udry and Anagol, 2006) found that their implicit discount rate was 60 percent. These enterprises also lack the scope to collateralize assets such as solar panels due to deficiencies in physical security, the legal environment, and the financial sector. Not only is distributed solar power very capital intensive, it is also skill-intensive. Solar panels require maintenance and this in turn requires a distributed network of service technicians. The scarcity of both technicians and the managerial capacity to organise distributed service provision in Africa reduce the effective life of solar panels and so accentuate their capital intensity.

Hence, despite its advantages, solar power is currently only viable for households and small firms in conditions of extreme shortage and with a very high shadow-price of energy. It may be a valuable technology for bringing power to outlying villages but not for urbanites who, by 2030, will constitute the majority of Africa's population. This is confirmed by Deichmann et al. (2011) who study the costs of decentralised renewable energy sources, primarily solar PV, relative to alternatives that require expanding the area covered by the grid. Looking at Ethiopia, Ghana, and Kenya, they conclude that decentralised sources are cost competitive in remote regions, but only for a minority of the population. While the cost of solar panels will continue to fall very sharply the cost of storage of power for night-time use will remain high. Looking at technical change scenarios over the next 20 years Deichman et al. suggest that solar PV will not be likely to cover more than 10% of households in the countries they study.

[9] These discoveries, if combined with sustained high resource prices and improved governance, will relax the constraint of shortage of public funds for investment.

[10] Financial Times, 2012.

[11] See Limao and Venables (2001).

[12] We concentrate on solar PV. For a discussion of concentrated solar power see IPCC (2012).

2.5. Hydro-power abundance

Africa has a major natural advantage in hydropower because it has immense high-altitude areas onto which the water vapour gathered over the Atlantic falls. The run-off from this rainfall through the Congo, Niger and Zambezi rivers could support several mega-dams, significant projects in the upper Nile (Ethiopia and Uganda), and numerous smaller schemes. At present some 38 percent of Africa's electricity is from hydro-power (close to 70 percent excluding South Africa, Eberhard and Shkaratan, 2012), and estimates suggest potential for a twelve-fold scale-up. Hydro is the most promising of the renewable energy sources for large scale development. As indicated in Table 1, it is relatively cheap and, while most costs are sunk in construction of the dam and generating equipment, capital costs per MWh are much less than for other renewable technologies. A considerable expansion of hydro capacity is planned or underway, including 10 GW of capacity in Ethiopia; IPCC (2012) reports forecasts of a trebling of African hydro capacity by 2035.

However, in this sector also, Africa's lack of governance capacity creates potential problems. The very high ratio of sunk capital costs to recurrent costs makes hydropower acutely exposed to the time-consistency problem. The usual tension between the sunk cost of a private investor and the interest of the host government is compounded by the multinational nature of much of the demand for hydropower. Africa is fragmented into 54 countries, and hydro potential is concentrated in a few of them; a full 61 percent of Africa's hydropower potential is found in just two countries, the DRC and Ethiopia (Eberhard et al., 2011). Successful development therefore requires extensive export of hydropower to neighbouring countries, but importing countries have a strong incentive to renege on deals struck prior to investment in the exporting countries. Four regional power pools have been set up to facilitate this trade, but significant levels of trade only take place in the South African Pool, this largely between Mozambique and South Africa.[13] Only the unusually strong governance and hegemonic position of South Africa within its sub-region make commitments credible. Eberhard et al. (2011) estimate that cost savings approaching $3 bn pa are currently being foregone by low levels of intra-regional trade in power in Africa.

The most notable example of investments that are blocked by these political obstacles is the Grand Inga hydroelectric project on the River Congo. If fully implemented this would have a capacity of 39 GWs, double the size of the Three Gorges mega-project in China. However, this natural advantage collides with economic and political disadvantage. At the present level of African power usage, Grand Inga would meet a third of the region's electricity consumption. To reach such a large market would require transmission lines from the Democratic Republic of the Congo, where the power would be generated, through Zambia, Zimbabwe and Botswana, to the major source of demand in South Africa. Understandably, the considerable potential for hold-up has deterred private investment for decades.

2.6. Land abundance and biofuels

As with the abundance of sunlight, Africa's land abundance is a natural advantage with potential for energy production. Sub-Saharan Africa's population density is low, just one-tenth that of India's. Currently, much African land lies idle, being uneconomic at prevailing prices and technologies: on one estimate, land in sub-Saharan Africa which is potentially available for new agricultural use amounts to 200 million hectares.[14]

Since the recent spike in commodity prices there has been an upsurge in international demand for African land; while most of the deals have been for food production, some have been for bio-fuels.[15] This has been in close competition with food production, since Africa is a substantial net importer of food and the majority of bio-fuel comes from sugar cane which requires high-quality well-watered land equally suitable for food crops. This suggests that, at least with current technologies, it is inappropriate to substitute bio-fuel production for food. If the cultivation of bio-fuels for export appears uneconomic in African conditions, how might we account for the post-2008 surge in international demand for African land to be used for this purpose? One explanation is that much of this demand may by speculative (Collier and Venables, 2012). While current cultivation may be valueless, as reflected in the token prices commonly paid by international investors, the acquisition of a long lease on the land may be valuable since it includes an option value which depends upon the course of future food and energy prices.

2.7. Forest abundance and biological sequestration

Africa's enormous rainforests confer another energy-related natural advantage, namely the potential for biological sequestration of carbon. The sequestration generated by the preservation and expansion of these forests could potentially be sold on the incipient global market in carbon credits. However, the region's three disadvantages in the economic endowments that are intensive in the activity again offset this natural advantage. The market in carbon credits requires a high degree of accountability: carbon sequestration must be verifiable and certifiable. As a result it is very intensive in regulatory capacity. Indeed, the regulatory problems noted above are dwarfed by those faced in forestry, since government must have effective control over vast tracts of inaccessible land. The core of Africa's rainforest is in the Democratic Republic of the Congo, which is ranked near the bottom of Africa's governance indices.[16] To date, only Gabon has put in place the basis for verifiable custody of its rainforest.

3. Energy usage

Africa's natural endowment creates both advantages and disadvantages in energy usage. The evident advantage is that given its climate less energy is needed for heating than in the industrialised economies. Offsetting this, the massive size of the region relative to its population increases the need both for energy in transport and for the transport of energy. This is compounded by three further characteristics: the continent lacks navigable rivers; its population is disproportionately distant from the sea as a result of the prevalence of malaria in coastal areas; and it is the least urbanised region.

The fundamentals of African energy usage reflect both the natural disadvantage posed by a dispersed population and the economic and governance disadvantages in energy generation discussed above. As a result, the central feature of African energy usage is extreme scarcity for both households and firms: the shadow price of energy is very high. Households typically have no reliable source of power other than for cooking. The lack of adequate lighting has evident consequences: for example, children are not able to do homework in the evening: perishable food cannot be refrigerated, leading to illness and restricted diets. Firms resort to high-cost self-generation, and surveys routinely find that the shortage of power is their foremost concern.

An important manifestation of these problems is users' reliance on off-grid power generation. Because public grid-supplied power is highly unreliable and private grids are usually prohibited, power generation has been turned into a subsistence activity. Private firms of all

[13] The Cahora Bassa dam in Mozambique was built by the Portuguese in the 1970s and transmits 2 GW of HVDC power to South Africa. It was out of action for most of the 1980s.

[14] Deininger and Byerlee (2011). The criterion of potential availability is non-cultivated, suitable for cropping, non-forested, non-protected, and with population density of less than 25 people per km^2.

[15] See http:/landportal.info/landmatrix for documentation of these deals.

[16] For example, on the Ibrahim Index of African Governance for 2011 the DRC is ranked 50th out of 53 countries.

sizes generate their own electricity using diesel generators, at high cost and absorbing capital that could have been used for other investments. The problem has been persistent: a study of small firms in Nigeria found that three quarters of their entire capital stock was tied up in generators (Lee and Anas, 1991). Further, self-generation is only a partial solution. The resulting inability to exploit scale economies sharply increases unit costs. Typical electricity production costs in Africa are around 12 cents per KWh, about twice that in the developing world and almost as high as in the OECD (Eberhard et al., 2011). This correspondingly increases the carbon emissions per unit of energy generated.

Most conventional mitigation efforts aim to green energy usage by raising the marginal cost of carbon-based power, thereby inducing its consumption to be lower than it otherwise would have been. Given the African starting point of a very high shadow price, such a reduction would be particularly damaging. Indeed, it is a vital matter that Africa substantially reduces its energy costs. The region has yet to break into global manufacturing and will not be able to do so while the electricity costs to its firms are significantly higher than those in China. Given the region's exceptionally rapid population growth, job creation in manufacturing, as has occurred in Asia, would be socially stabilising as well as directly productive. Africa cannot afford cost-increasing mitigation: any measures that it takes to green its energy usage must also be cost-reducing.

Paradoxically, although African firms and households are acutely short of energy, they use it in ways which by international standards appear highly inefficient. This is not because firms and households are failing to optimise, but rather because, as with energy generation, the prices which they face for capital, regulation and skill are very different from world prices.

3.1. Capital

Energy usage faces the African decision taker with numerous trade-offs between capital investment and recurrent inputs. At the household level the most striking example is the choice of stoves for cooking. The cheapest stoves use wood or charcoal which are becoming increasingly expensive as wood cover is depleted. Kerosene stoves are more expensive than charcoal-burning stoves, and LNG stoves are more expensive still, mainly because of the initial cost of purchasing a canister. The resulting choice is thus sensitive to the discount rate, and the consequent prevalence of wood and charcoal-fuelled cooking has substantial consequences for both the local and global environment. A less obvious but pervasive household energy-saving investment choice is that between a bicycle and walking to work: many millions of Africans walk long distances to work because they cannot afford a bicycle which would substantially reduce their daily energy needs. At the firm level, the equivalent trade-off between capital investment and expenditure on fuel is most evident in the choice of transport equipment. Very old trucks are highly energy-inefficient, with both high expenditure on fuel and high emissions, yet African firms do not replace such vehicles because of the acute capital constraints noted above.

The high discount rates facing African households and firms have material consequences for mitigation. Fig. 2a and b show suggested marginal abatement cost (MAC) curves for Kenya. Fig. 2a shows the cost curve when a discount rate of 4 percent is used, which might be taken as representative of the international cost of low-risk capital. Fig. 2b shows the cost curve when the same opportunities are evaluated using a 30 percent discount rate, which is reasonably representative of the high rates prevailing amongst African households and small firms.[17] With a discount rate of 4 percent there are many options which are cost-reducing even before any benefits of reduced carbon emissions are considered. The most significant gains come from replacing the large stock of very old vehicles and from switching from energy-inefficient, charcoal-burning stoves. However, the sensitivity of this to local costs is made clear by comparison with the cost curve using a 30 percent discount rate (Fig. 2b). Many options, such as the scrapping of old vehicles and micro-hydro, go from negative cost to positive cost. All become more expensive; at 4 percent around 4Mt C02e mitigation is negative cost, at total cost saving of \$600 million; at 30 percent this falls to 2Mt CO_2e at cost saving of \$100 million.

Most energy use decisions are taken in a highly decentralised way, by firms and households. The Figures illustrate the sensitivity of these decisions to discount rates, explaining why apparently superior technologies have not already been adopted, and pointing to the difficulty of implementing these emissions reducing changes.

3.2. Governance

The argument and figures of the preceding sub-section are based on discount rates and capital intensity, but transition to green energy use also requires skills, complementary public goods, and regulatory measures. There is a wide ranging set of issues, and we touch on a few of them.

There are some contexts in which the combination of market failure and governance failure militate against efficient energy usage. One example is wood. As in Fig. 2, some of the largest reductions in emissions in Kenya would come from cooking, either by converting to another fuel or through more efficient use of wood. The use of wood for cooking in Africa is an economic rather than a cultural phenomenon: wood is cheap. The reason why is not that it is abundant, but that it is being rapidly depleted. In turn, rapid depletion is due to weak property rights: wood is cut excessively because it is a tragedy of the commons. As Ostrom (1990) has shown, in stable socio–economic conditions local communities can evolve rules of use for common property that ensure sustainability. However, in respect of wood stocks, very rapid African population growth and rising energy costs have stressed these systems, and weakened informal rules have not been replaced by formal law. Globally, the most striking example of how a difference in governance capacity affects the use of wood for fuel is the contrast between Haiti, which is analogous to the more weakly governed African states, and the Dominican Republic which ranks with the best-governed states in Africa. The two countries share the same island and initially each half had similarly extensive tree cover. Yet currently tree cover in Haiti, where cooking continues to be by means of charcoal, is only around two percent whereas in the Dominican Republic, where subsidies were used to pump-prime the switch to LNG and kerosene, it is around 37 percent.

On a much larger scale, Africa's difficult governance has increased the emissions intensity of economic activity by affecting location choice. Africa's dispersed population increases emissions intensity: globally, high-density urban residence tends to be considerably less emission-intensive than low-density, rural residence. However, many African cities have lower population density than Asian cities of similar size, a characteristic generally attributed to two factors. One is the poor development of land markets, and the other the lack of public provision of infrastructure needed for high density living. These are further aspects of Africa's regulatory capacity, and suggest that the prospects for higher density low emission cities are poor.

Provision of public utilities also matters for energy use, both directly and by supporting adoption of new techniques. Using evidence on the adoption of hybrid maize in Kenya, Suri (2011) shows how households which would have very high gross returns from adoption rationally choose not to adopt because of offsetting high costs attributable to poor infrastructure. An example of poor quality and energy inefficient infrastructure is the decline in Africa's rail network. As an enormous landmass Africa is well-suited to railways, as reflected in

[17] Recall that whereas 30 percent might seem high, it is below the 60 percent estimated for small firms by Udry and Anagol (2006) and also below the interest rates typically charged to households by informal money lenders.

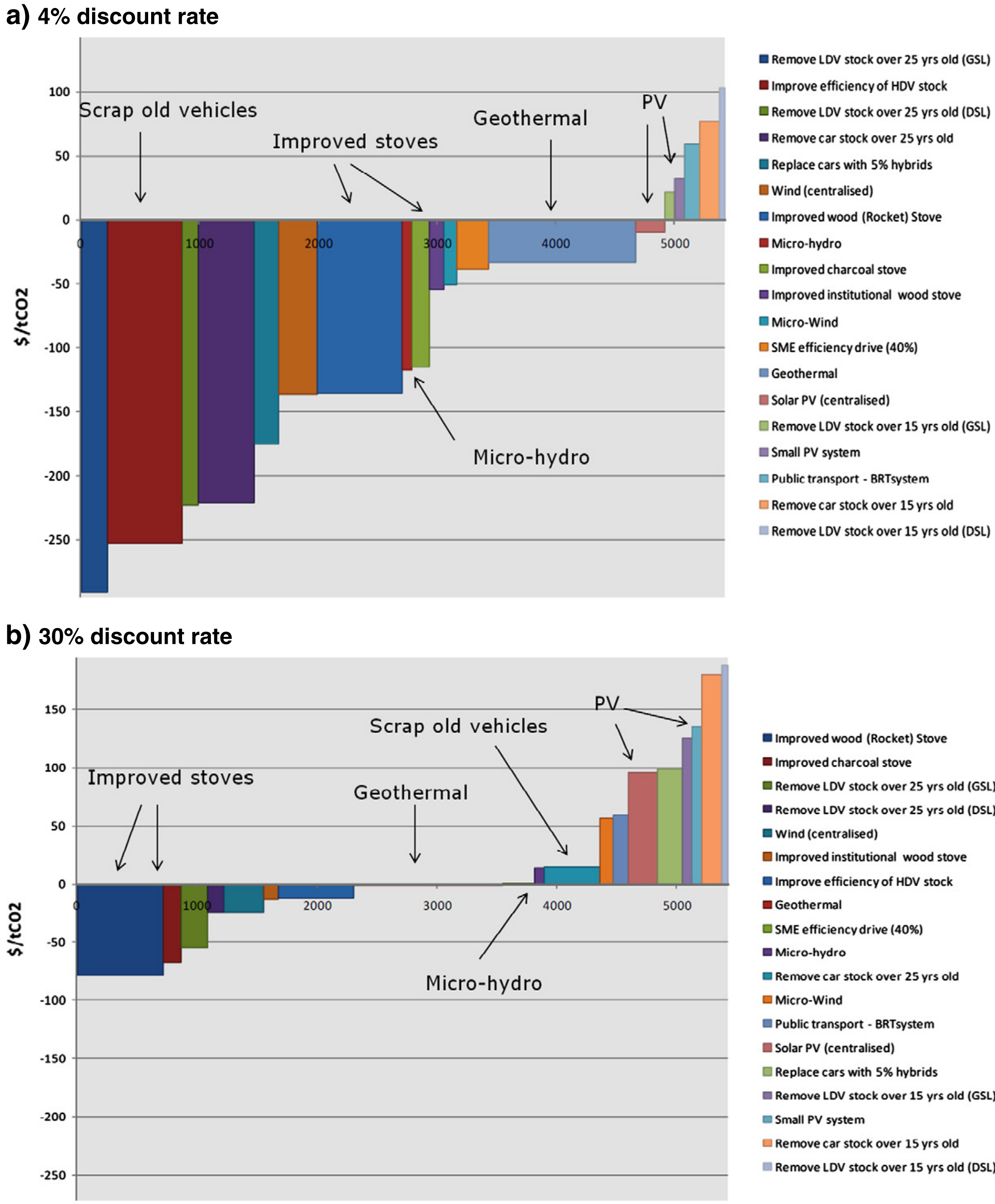

Fig. 2. Indicative MAC curve of selected abatement measures for Kenya in 2020. (a) 4% Discount rate, (b) 30% discount rate Stockholm Environment Institute, 2010. Horizontal axis is 5.5 $MtCO_2e$. GSL, gasoline; DSL diesel.

heavy colonial investment. However, railways are a network activity and so face regulatory challenges analogous to electricity. Run as public monopolies the African rail networks gradually deteriorated due to the shortage of managerial skill, but to date the problems posed by regulating private investors have proved no more tractable in rail than in power. As with the power sector, weak regulation has been compounded by the capital intensity and longevity of rail investment. By default, as a result of the decline of the rail network the key transport arteries have switched to road haulage. Yet, especially with low-quality roads and an old vehicle stock, the energy efficiency of long distance road haulage is far less than that of an efficient rail system.

4. Latecomer advantage

Africa will be the last region in the world to embark on massive expansion of its power capacity. It therefore faces the prospect of avoiding a heritage of old and dirty capital equipment and of moving directly to new technologies that are both greener and more efficient. The ability to use more modern technologies is of direct benefit to

Africa, as well as to the environment, although the uptake of these technologies will depend on complementary inputs and comparative costs. Furthermore, since new technologies are changing rapidly, there is also a question of timing.

Many green technologies will not attain levels of economic viability for several decades, suggesting that there is advantage in postponing rapid expansion of the energy sector until new technologies are available. However, Africa's circumstances are such that delay is particularly expensive. As we have seen, the social discount rate is high. Furthermore, current energy scarcity means that the marginal social value of energy is far higher than in other regions. Surveys of African firms routinely show the lack of power to be their foremost concern. Almost all firms rely upon self-generation by means of diesel generators, but this is a very high-cost form of power because scale economies are not exploited which in turn harms economic development and job creation, particularly in manufacturing. Even with the option of high-cost self-generation, production and other economic activities are often disrupted by power outages, so that the shadow price of electricity is very high. Anything that postpones development and causes the quantity of power used to be less than it otherwise would have been is therefore more expensive in Africa than in other parts of the world. The potential green advantage of being a latecomer is therefore stymied by the urgency of installing new capacity.

A general analytical point underpins these remarks. Given falling costs in new technologies it may be efficient to postpone power sector investments; however, the optimal delay for low-income countries is less than it is for high income countries. The appendix to the paper outlines a model to make this point, formalised as the following question. Suppose that it is known that a new clean technology becomes viable at some future date, T. How far in advance of T should a country stop investing in old dirty technology, suspending investment until the clean technology is available? The benefits of this moratorium come both from the direct cost saving in postponing investment (this being larger for a country with a high discount rate), and from carrying less old technology which incurs losses following date T (when it competes with new technology). However, the cost is the output foregone during the period of delay: the investment moratorium causes capital stock and output to fall below what they otherwise would have been. While some moratorium is always optimal, the magnitude and cost of this loss of output are greater the lower is the initial capital stock; the appendix illustrates how this trade-off is resolved, with the optimal investment moratorium being shorter in low income and fast growing economies.

In summary, there are latecomer advantages from which Africa will benefit as it can access new technologies during a future investment surge. Since many of these technologies are not yet viable there is an inter-temporal substitution argument, suggesting that investment should be postponed until new techniques become available. The argument is less applicable to Africa than it is to higher income countries because of Africa's current low capital stock and energy shortages.

5. Exploiting the difference between domestic and international costs

We have suggested that despite the considerable importance for Africa of mitigating global warming, it may well be appropriate for the region to lag rather than lead in adopting green development strategies. To summarise, Africa is short of energy and so should be expanding energy production and use. Africa's endowments – shortages of capital, skills, and governance capacity – make most of the green options relatively expensive, while abundance of hydro-carbons makes use of fossil fuels relatively cheap. However, there are promising sectors, notably hydro-electricity. Furthermore, relative scarcities and prices are not immutable. They can be changed in two sorts of ways. One is by opening up and improving markets, so that relative prices and costs in Africa are brought closer to those in the rest of the world. The other is by changing the endowment directly by supplying scarce factors, either through markets or through development assistance.

5.1. Markets and prices

The first point is that better integration into the world economy can narrow international price differences. As described in any international economics textbook, the impact of endowments on local costs and prices depends on the extent to which a country or region is open to the world economy. Specialisation through trade enables countries to economise in the use of endowments in which they are particularly scarce, releasing them for use in non-tradable activities such as energy generation in which they are critical. Integration into factor markets potentially enables Africa to attract the capital, skills and technology embodied in foreign direct investment, needed for green energy.

Complementing greater integration with global markets, greening would be assisted by improving markets within Africa. In energy usage, as suggested by Fig. 2a and b, there is considerable scope for reducing emissions if the discount rates faced by many households and small enterprises can be brought down. Occasionally, this can be done in a technology-specific way, for example by subsidising the cost of switching to an LNG-burning stove. However, since energy-inefficient constraints on investment decisions are pervasive, generally the more appropriate approach might be to improve the operation of financial markets. Underlying the persistent shortage of capital in Africa, despite the global abundance of capital, is a series of market failures due to poor financial information, weak corporate governance, and badly functioning legal systems. International support for greening African development can contribute to assisting Africa make more efficient use of its own resources, by mitigating these market failures and thereby deepening financial markets.

5.2. The supply of capital

Mitigation policies in industrial countries will impose substantial additional costs on firms and households. Yet Africa has opportunities for emissions reduction which, at international prices of capital, offer far better value. Hence, it would be cheaper for the firms and households of the industrialised world to provide the capital to finance African emissions reductions than to achieve the same reductions by domestic actions. One instrument to achieve this is the Clean Development Mechanism, yet its uptake in Africa has been extremely low (it accounts for 2% of registered projects), precisely because it is intensive in other capabilities which are scarce in Africa.

Another mechanism is official development assistance, which could be used to address the divergence between investment choices at domestic and international prices. In power generation, the coming surge in investment could be green, but this is not assured by current prices and costs. It is cheaper for the international community to pay for the installation of green technology in Africa's new plants than to retrofit it in existing Northern plants. A second Africa-specific opportunity in generation is for international public finance to subsidise the cost of switching from gas flaring to either LNG or gas-fired electricity generation. An alternative to a direct subsidy on the capital costs might be to reduce the domestic regulatory risk faced by investors through guarantees. A third Africa-specific opportunity would be to provide international public subsidy or guarantees for the hydropower mega-projects. Ironically, for over a decade environmentalist NGOs have effectively blocked the use of aid to fund dams, primarily to protect the population resident in areas to be flooded.

Aid agencies have long experience in both capacity-building and in skill provision: around a quarter of aid is provided by means of technical assistance. While such assistance can often reasonably be criticised as supply-driven, it does attempt to address Africa's chronic shortage of skills.

5.3. Assisting governance capacity

In addition to directly providing international public capital, there may be scope for politically acceptable assistance in the provision of international governance. Improved governance would in turn support higher levels of investment. For example, Chinese investments in Africa are already routinely protected by the legal device of appeal to international Dispute Settlement Boards, composed of a membership agreed in advance between the parties and conducted under the law of England and Wales. A different approach is international risk insurance combined with leverage for recovery, as exemplified by the Multilateral Investment Guarantee Agency (MIGA), the political risk insurance arm of the World Bank. MIGA is able to charge low premiums because with rare exceptions it has been able to recover from governments those investor claims against them on which it has determined that the evidence warrants payment. While Dispute Settlement Boards are used for Chinese investment in Africa, (and for FDI in China itself), other potential investors in Africa have seldom tried to negotiate it, perhaps because they operate at a smaller scale and lack the direct access to presidencies available to China. Similarly, MIGA currently insures only a small proportion of African FDI. There is thus considerable scope to expand such risk-mitigating uses of international governance.

6. Conclusion

Superficially, both geography and history appear to have made Africa particularly well-suited for green energy. Sunshine, water, land, forests, and being a latecomer to installation of much modern infrastructure, all confer significant advantages. However, energy generation and usage are economic activities with other distinctive factor intensities. In particular, energy generation, energy saving, and carbon capture are intensive in capital, governance capacity and skills. Unfortunately, all of these factors are scarce in Africa. Natural endowments and these other factors are complementary inputs: energy cannot be produced purely from sunshine and water, nor captured purely by forests. Hence, these intensity-derived factor scarcities offset the advantages conferred by natural endowments and are often decisive. Similarly, the historic advantage of being a latecomer to installation of generating capacity is offset by the historic disadvantage of the acute energy scarcity inherited from past under-investment: Africa cannot afford to wait for further developments in green technologies. Nevertheless, there is scope for Africa's natural advantages for green energy to be harnessed to global advantage. But to do so will require international action that brings global factor endowments to bear on Africa's natural opportunities.

Appendix

In the absence of the new technology, the economy is on a growth path with capital stock K_t^*. Capital stock, labour force, and output all grow at constant rate g, so $K_t^* = K_0 e^{gt}$, and the rate of depreciation is δ. The clean technology becomes available at known and certain date T; after this date the value of output from dirty technology drops by factor γ (e.g. due to carbon tax). θ is the endogenously chosen date at which it is optimal for the economy to stop investing in dirty technology knowing that clean technology becomes available at T. The capital stock (and hence also output) will deviate from K_t^* during interval $t \in [\theta, T]$, and takes value denoted as $\tilde{K}_t$. The capital stock reverts to K_t^* after date T.

The costs and benefits of the deviation come in three parts. First, postponement of investment. Investment on the original path, $I_t^* = (g+\delta)K_0 e^{(g-r)t}$, does not take place during the moratorium, but the deficit is made up at date T when capital jumps from $\tilde{K}_t$ to K_T^*. The saving is $A = \int_\theta^T I_t^* e^{-rt} dt - \left(K_T^* - \tilde{K}_T\right) e^{-rt} = \int_\theta^T K_0 (g+\delta) e^{(g-r)t} dt - K_0 \left[e^{gT} - e^{g\theta - \delta(T-\theta)}\right] e^{-rT}$.

Second, dirty capital stock remaining at date T takes capital loss γ, so comparing paths with and without delay, the benefit of delay is: $B = \gamma\left[K_T^* - \tilde{K}_T\right] e^{-rT} = \gamma K_0 \left[e^{gT} - e^{g\theta - \delta(T-\theta)}\right] e^{-rT}$.

Third, the value of lost output is:

$$C = \int_\theta^T \left[F(L_t^*, K_t^*) - F\left(L_t^*, \tilde{K}_t\right)\right] e^{-rt}$$
$$= \int_\theta^T A_0 \left(L_0 e^{gt0}\right)^{1-\alpha} \left[\left(K_0 e^{gt0}\right)^{\alpha} - \left(K_0 e^{g\theta - \delta(t-\theta)^{g\theta - \delta t - \theta 0}}\right)^{\alpha}\right] e^{-rt} dt$$

where F is the production function, and the second equation uses Cobb–Douglas technology with capital share α and productivity A_0. The net benefit from delay is therefore $S = A + B - C$.

Parameter values are $\alpha = 0.33$, $\delta = 0.05$, $g = 0.025$, $L_0 = 1$, $p = 1$, $\gamma = 0.5$, $T = 20$, $A_0 = 0.3$. r is set equal to the marginal product of capital net of depreciation, $r = A\alpha K_0^{\alpha-1} - \delta$. The benchmark case is $K_0 = 1$, implying $r = 0.05$ (A_0 chosen to give this value of r). The alternatives are $K_0 = 0.25$ (implying $r = 0.2$), and $K_0 = 0.25$, $g = 0.05$. The table below gives the optimal length of the moratorium for given values of the initial capital stock and growth rate.

Initial capital	Growth rate	Optimal moratorium, $T - \theta$, years	Share of green capital stock immediately after T, and 10 years after T
$K_0 = 1$	$g = 0.025$	8	45%, 74%
$K_0 = 0.25$	$g = 0.025$	4	26%, 65%
$K_0 = 0.25$	$g = 0.05$	3	26%, 73%

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