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The Post-Copenhagen Roadmap Towards Sustainability

Differentiated Geographic Approaches, Integrated Over Goals

Climate change will bring economic, social and environmental costs at scales beyond any other human experience (IARU, 2009). Studies imply that humanity must reduce CO_2 below its current atmospheric concentration if we are to preserve a planet like the one we are now adapted to (Hansen et al., 2008). Considerable action has been taken since the Kyoto protocol was adopted in 1990 and ratified in 2005, but emissions continue to accelerate with potentially fatal effects. In fact, considerable ambivalence surrounds the Kyoto protocol. On the one hand, it is the only current substantial international effort to mitigate dangerous climate change. On the other hand, it lacks ambition. Its instruments mostly rely on complicated financial incentives, while mitigation focuses on single-source, context-detached, quantifiable and technology-oriented cases.

The result is a piecemeal approach. For example, as the single most relevant instrument under Kyoto, the European emissions trading scheme has succeeded in imposing a price on carbon but has also put windfall profits into polluters' pockets. Meanwhile, the Clean Development Mechanism (CDM) can reduce emissions at low cost, but does not contribute significantly to sustainable development (Olsen, 2007). At present, because the incentives are badly aligned, validation and verification of CDM projects cannot perform adequately and the additionality of a significant number of projects is in question (Schneider, 2007). In addition, the

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Kyoto framework requires single-source quantification, which is very difficult for some sectors, particularly transportation where it is very difficult to determine emission reductions, e.g. through reduced levels of motorization; other measures often have high transaction costs. For all these reasons, then, to achieve the required and ambitious reductions in emissions, the current piecemeal approach must be complemented by a more all-encompassing plan or program.

In response, we suggest a systemic approach in which mitigation measures are integrated across a set of sustainability goals, so they can be used to tackle local environmental, economic and social issues simultaneously, making them far more effective. Meanwhile, they should be specific to location, i.e. adapted to local geographical situations and cultural knowledge.

The beneficial side effects of climate change mitigation, the so-called co-benefits, are so persuasive that we cannot afford to ignore them. Mitigation policies nearly always affect other domains or interact with other policy dimensions. In the economic domain, for example, fuel efficiency standards will impact the automobile market and energy security. Equally important are the consequences for other environmental and social causes: Mitigation policies offer considerable benefits in air quality, biodiversity, and health, and they counteract energy inequality. In fact, in specific cases, the local or regional co-benefits outweigh the benefits of climate change mitigation by an order of magnitude. Because climate change mitigation is a public good, no single party takes on sufficient responsibility for it, and not enough is being done worldwide to protect the climate. From this agent-based perspective, co-benefits can be a game-changer for localized climate action: if the co-benefits of mitigation, such as improved air quality, manifest themselves locally, then they increase the incentives to act.

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Climate change mitigation and adaptation must also be seen in terms of development and alleviating poverty. Reconciling social justice with environmental protection and climate change mitigation will be crucial to effect global action (Baer, et al., 2000; Roberts & Parks, 2007). While OECD countries invest in mitigation policies, developing countries can gain the capabilities they need to choose low-carbon development paths. But development itself requires economies of scale that cannot be jump-started with meager development aid, often conditional on purchases and services from donor countries. Adaptation funds can overcome this financial barrier. For example, money raised from taxes on international air and maritime transportation and gathered by an international agency could be used to finance forest protection and adaptation measures.

When mitigation policies are designed and implemented from an integrated perspective, the regional or national population and electorate benefit directly. Not only does such an approach promote sustainability; in many cases, it also makes projects politically feasible. In fact, much of the mitigation action we are seeing at present can be attributed to local policies that are not necessarily motivated by climate change.

Mitigation action is also inherently spatial. The co-benefits are nearly always local or regional and differ from one place to another. Obviously, different geographic locations offer varying possibilities for renewable energies and different mitigation options. Because land-use patterns and population density are path-dependent, a differentiated approach is required. When technologies and infrastructures are adapted to the situation in a given area and become embedded in that context, they also become more useful because they are (re-)aligned with local cultural practices. In the rest of this paper we illustrate these points, using the examples of land-use change, small-scale and urban electricity supply, and the sustainable development of cities. Then we discuss the implications for a general framework of measurement and investment.

LAND-USE CHANGE AND FORESTS

Recent reports have illustrated that land use, and changes in it, is a major factor in the emissions and absorption of greenhouse gases (GHGs). Because land-use change has many causes and leads to a variety of consequences, it is hard to understand and act on it without understanding its context.

What is the issue? During the 1990s, deforestation accounted for about 25% of all anthropogenic greenhouse gas emissions (Houghton, 2005). These emissions are hard to measure, however; across all sectors, the uncertainty about the magnitude of emissions is highest for land-use change. Indeed, we are far from completely understanding deforestation, degradation and the changes in land use that cause GHG emissions. We do know that these emissions are probably high, so any effective climate regime must ensure that forest degradation is avoided. Of all the mitigation options related to forests, preservation has the largest and most immediate impact on carbon stocks in the short term. And preserving forests is more important than reforestation, as nothing can substitute for an intact ecosystem. Crucially, if forest degradation proceeds beyond a certain threshold, it may induce irreversible destruction of the rain forests.

Intact forests provide many co-benefits. They are more resilient against climate change, guarantee valuable biodiversity, and provide additional ecosystem functions such as water services (Noss, 2001). Forests also provide commercial prod-

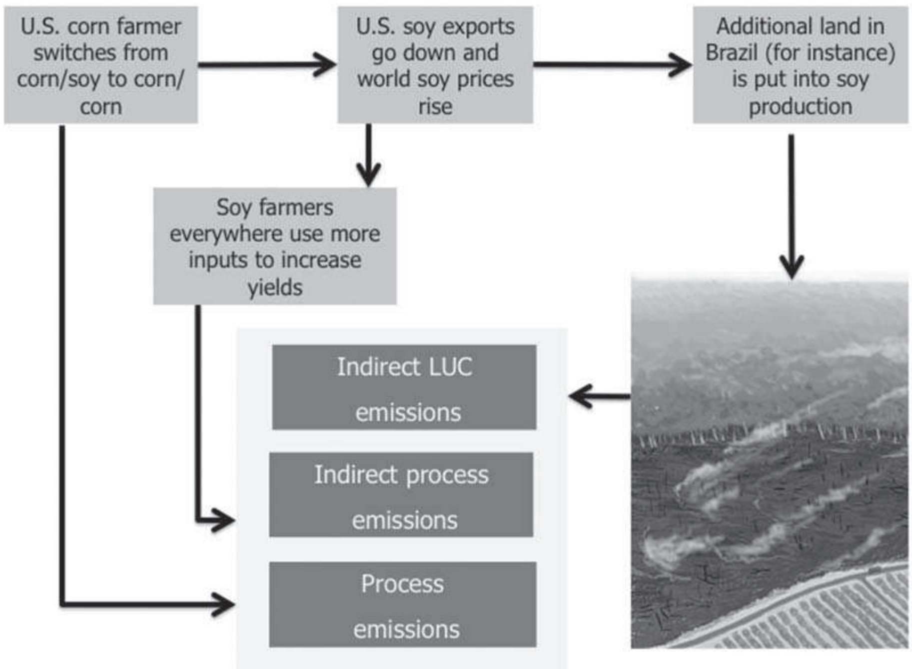

Figure 1. Changes in land use change may cause large emissions of GHGs.

ucts, such as timber, and provide opportunities for tourism, as well as non-commercial goods such as firewood for home use, drinking water, gums, resin, honey and fodder. Forests with watersheds purify water and protect downstream residents from floods, droughts and sediments, prevent erosion and provide wildlife for hunting. They can also store a significant amount of carbon and house significant biodiversity. Thus the potential commercial benefits of land-use changes in watersheds or other ecosystems must be weighted against a complete accounting of all the social benefits. These effects translate directly into macroeconomic loss when deforestation occurs. For example it is estimated that developing countries lose $15 billion each year due to illegal logging. That amount is eight times the total amount of international development aid to the forest sector.

What drives deforestation? The phenomenon of deforestation is entangled in both global and local market dynamics and institutions. On a global level, research emphasizes the indirect changes in land use that result from increased bioethanol production. For example, in response to higher prices, farmers worldwide have been converting forests to cropland to replace the grain that has been diverted to biofuels. The effects of this shift may be so significant that the net savings in GHGs will only occur after more than 150 years (Searchinger et al., 2008). The exact numbers are highly disputed, and there is a lot of uncertainty around the magnitude of indirect land-use change (iLUC) effects. However, there is agreement that iLUC can be very important and thus cannot be ignored. One specific aspect is that agrofuel production increases GHG emissions, mostly due to land-use changes when production begins, and thus has an immediate adverse impact on the climate (O'Hare et al., 2009). Some of the effects of this dynamic are summarized in Figure 1.

Furthermore, the current system of resource-intensive cheap meat production builds on the substantial demand for crops and may indirectly increase the pressure on primary forests and augment agricultural emissions. Local factors that drive deforestation include poverty, local demand for agricultural land and firewood, large-scale commercial cattle farming and dependency on exporting agricultural goods. Altogether, the decline in rainforestsis determined by a combination of various proximate causes and underlying driving forces (Geist & Lambin, 2002). Some of these causes are robust geographically, such as the development of market economies, but most are specific to their regions. Thus we must analyze cases individually.

Further scientific research is crucial in particular areas. The magnitude of the emissions related to land-use changes, combined with our lack of quantitative understanding about the interdependencies mentioned above, highlights the need to evaluate land-use systematically. Germany's Advisory Council on Global Change (WBGU, 2008) suggests three key areas for research:

- Enhance our base of knowledge about global land use, using high-resolution GIS data to determine vegetation cover, soil conditions and agricultural usage.
- Determine the amounts of GHGs that result from various land uses, including complete pathway analyses for particular uses, e.g. bioenergy.
- Investigate land-use competition and develop a land-use management system that takes into account different objectives, especially the basic need for food security.

It is widely recognized in science and politics that reducing or avoiding deforestation is a critical component of any international regime to reduce emissions. From the perspective we take in this article, two issues deserve particular emphasis. First, any deforestation agreement will address those countries that possess significant tropical rainforest cover, such as Brazil, Indonesia and Congo. However, with respect to a global framework on forests, the Annex I (industrialized) countries should not be relieved of their obligations—or deprived of the chance to use their potential. Russia, Canada and the U.S. have the world's largest primary forests, after Brazil. Some European countries are contributing significantly to GHG emissions because of land-use changes, e.g. by increasing their demand for wood. On the other hand, the U.S. can potentially sequester at least 150 million metric tons of carbon via reforestation (Rhemtulla et al., 2009). Hence, instead of only considering the deforestation of tropical rain forests, we should be applying an integrated concept of land-use change that includes the OECD countries (Mollicone et al., 2007). Second, a deforestation agreement clearly cannot solve all problems, but it will be effective only if the co-benefits and externalities are fully understood. In particular, it does not help to avoid GHG emissions only at one

How sustainable are biofuels?

Sustainable bioenergy has significant potential but also presents particular risks, as we show in this article. As the increased cultivation of crops for energy connects the rapidly-growing worldwide demand for energy to global land use, unregulated bioenergy development increases the likelihood of conflicts over land use. Some uses of land are essential, and irreplaceable, such as food production and the conservation of biodiversity and biogeochemical cycles; they must have priority over the production of biomass to generate electricity or transport fuels (WBGU, 2008). The utilization of waste and residues for energy generation is beneficial, causing very little competition with existing land uses, especially if energy crops are grown on land whose productive or regulatory function is limited. Furthermore, before cultivation begins, two conditions must be met: the interests of local population groups must be taken into account and the implications for nature conservation must be assessed. Cogeneration offers the most efficient use of bioenergy; in converting biomass to electricity it is more land-use efficient than biofuels (Campbell, Lobell, & Field, 2009). Policies that foster electromobility, i.e. support for electric cars, electric bicycles and appropriate infrastructures, are environmentally more beneficial than the current subsidies currently offered for biofuel production (Creutzig & Kammen, 2009).

specific point in time and space, if these emissions are then shifted to another place, or produced earlier or later; this phenomenon is called leakage. To avoid skewed incentives that encourage various parties to engage in gaming over emissions reduction within narrow system boundaries, a forest emission regime can be designed to promote the local co-benefits of forest preservation, i.e. by making everyone aware of the long-term economic value of forests rather than including only monetary incentives.

RURAL SETTLEMENT: SCALING UP SMALL-SCALE ENERGY SOLUTIONS FOR AFRICA

Small-scale technologies provide an often-underestimated potential for climate change mitigation both in cities and in rural areas; they can also promote low-carbon development.

Small-scale power generation, e.g. from solar radiation or biomass, can be efficient and produce little atmospheric carbon. At the same time it can be very important for local communities, by decisively combating energy poverty, reducing child mortality and providing crucial employment opportunities. Additionally, small-scale power generation is correlated with improved education and health services (Cabraal, Barnes, & Agarwal, 2005). Climate mitigation aside, these co-benefits provide sufficient reason to implement programs. However, there is no global silver bullet: successful solutions vary according to geographical location, latitude, needs and culture.

In this section we offer two concrete examples of small-scale power generation and co-benefits. First, solar electric systems, alone and especially as part of micro-grids, can provide substantial amounts of energy in rural areas and existing programs can be intensified. In Kenya, solar electrification has occurred at a faster pace than grid connection efforts; over 200,000 homes now have solar units and the figure is growing by 18% annually (Jacobson & Kammen, 2007). In other African countries, the rapid penetration of cost-competitive solar home systems is partially constrained by government subsidies on kerosene and propane fuels.

Second, biomass is an important source of energy, mostly consumed in cooking stoves. Worldwide, more than 90% of the bioenergy currently being used comes from traditional sources, such as wood and charcoal in cookstoves; 38% of the world's population depends on this form of energy, and 1.5 million people die each year from the pollution caused by open fires. Simple technical improvements to stoves can reduce many of the health risks posed by biomass use and meanwhile double or even quadruple the stoves' efficiency.

Newly designed charcoal stoves are far more efficient in both combustion and heat transfer than older models. Such cooking stoves, along with solar and plant-oil stoves, and other environmental management measures are not only beneficial in terms of energy efficiency; they can also lead to huge health benefits by reducing indoor air pollution (Ezzati & Kammen, 2002). Hence, these technologies address health, deforestation and greenhouse gas emissions at the same time that they provide energy at low costs. Even more importantly, improved and solar cookstoves can eliminate the emissions of black carbon, a crucial measure to reduce regional heating effects, particularly in the Himalayas. Hence, the large-scale deployment of cookstoves is very much in the interest of China, India and Southeast Asia, especially since they need to protect their long-term water security.

What does small-scale power generation look like from the grid perspective? Electricity consumption in Sub-Saharan Africa is only one 150th that of industrialized countries. Efforts to break up monopolies and liberalize energy generation and distribution in Sub-Saharan Africa increased the cost of the energy supply and contributed to energy inequality. Now, large-scale investments serving an elite minority receive the highest level of energy investments—at the expense of abundant, mature, and cost-effective small-scale renewable-energy technologies, such as solar energy, micro-hydro and improved biomass cooking stoves. However, innovative regulatory tools, including those for licensing, standards and guidelines, and metering and tariffs, have demonstrated the success of a new rural electrification regime (Kammen & Kirubi, 2008).

In these efforts, fee-for-service is a useful concept: An investor installs a micro-grid in a village and asks customers to pay fees for energy. In effect, the electricity provided is off-grid, the generation is small-scale, and the providers are individuals or communities. The costs are high but still lower than under the old regime as the grid does not need to be extended. For example, the Urambo Electric

Consumer's Cooperative in Tanzania outperforms the national utility in several respects: lower operation and maintenance costs, affordable tariffs, and improved customer service (Marundu, 2002).

Altogether, appropriate technologies for Africa are different than those for OECD countries. As most people have small incomes and little access to infrastructures, they can benefit greatly from technologies that are cheap, moderately efficient and simple to use; thus it is possible to reduce poverty with low-carbon technologies. In many cases, clever design trumps high-tech investment.

Although appropriate small-scale decentralized technologies have huge potential, however, they are only part of the equation. If economic well-being is to continue over the long term, the economies of scale must come with high productivity. Bringing economies of scale to Africa can be broken down into two tasks. First, economies of scale are usually reached in dense clusters of economic activity, mostly cities (Krugman, 1991). Such clusters of economic and academic activity also promote innovation, the key driver of economic well-being (Solow, 1957). An African center for appropriate technologies, such as one producing low-cost photovoltaics, could drive the economy of an entire region. Such a cluster would consist of a university, research laboratories, established companies, and funded start-ups. Substantial inputs of both financial and human resources from Annex-I countries could jump-start such an economy; local contribution should guarantee some sort of local ownership. Furthermore, trade agreements must be renegotiated to protect and foster these markets as the U.S. did in a far-sighted way to rebuild Europe after World War II (Jawara & Kwa, 2003). Second, economies of scale must be fostered as successful small-scale technologies are disseminated and deployed all over the continent.

ENERGY SUPPLY FOR CITIES IN INDUSTRIALIZED COUNTRIES

For OECD countries, the overall challenge is to overcome the reliance on carbon fuels, known as carbon lock-in, and to change structures so that a range of small and medium-sized technologies can be deployed, in a decentralized way, with the dominant contributors being wind farms, solar thermic and photovoltaic installations, geothermal power and (biomass)-cogeneration. Combined heat and power generation (cogeneration) is very efficient but still faces an adverse energy policy setting that favors large-scale, inefficient coal plants.

Also in OECD countries, small-scale technologies such as solar home systems, geothermal heat pumps and small cogeneration plants are already helping reduce the carbon intensity of electricity and heating, and increase energy security while providing additional employment opportunities. Soon, the price of electricity generated by photovoltaics (PVs) may drop enough to equal that of electricity from other sources, thanks to global investments of $200 billion (Farmer & Trancik, 2007); that would accelerate a huge market for renewables in all countries and on all scales. Smart-grid technologies will make it possible for the users of such systems to adjust loads, respond to unexpected demands, integrate power generated in decentralized locations, and become resilient to load fluctuations. These measures can make overall electricity usage significantly more efficient; the total monetary benefit is estimated to be $75 billion for the United States alone (Kannberg et al., 2003). In fact, changes in policy, such as pricing carbon according to such social costs, could help decentralize the energy supply even without further technological changes.

Large-scale technologies cannot be integrated into cities but they are part of their regional hinterland and are likely required to fulfill cities' energy needs. Three large-scale technologies can make a significant difference within the next decade: Wind parks, including off-shore wind; solar-thermal and/or PV; and geothermal. Wind is already competitive with conventional resources, so the private sector will invest in this technology as long as the financial market provides liquidity.

Solar thermal energy can contribute significantly to the near-term mix of energy from Africa, Europe, Iran, China, Australia, and the U.S. Once a reasonable price for carbon is established, solar thermal power plants will become viable in places as diverse as California and Botswana (Fripp, 2008; Wheeler, 2008). Concentrated solar power (CSP) has also been proposed and planned as the backbone of a transcontinental supergrid for the Middle East, Northern Africa and Europe.[1] A carbon price of only $14 per ton is enough to justify $20 billion in subsidies over ten years; by 2020 it can provide 55 terawatts (TWh) for EU-MENA (Europe, the Middle East, and North Africa) and make unsubsidized concentrated solar power competitive with coal and gas power generation (Ummel & Wheeler, 2008). Such supergrids will be more acceptable if local communities profit, e.g. with jobs, increased supplies of electricity, and desalinated seawater produced using waste heat from the power generation process.

Because geothermal energy can provide a baseload supply, that is, a constant, non-fluctuating energy supply, in contrast to wind or solar, it is attractive as part of the future renewable energy mix. Geothermal power, using conventional hydrothermal resources, can compete with coal, assuming moderate carbon pricing. For example, a project in Kenya has been able to reduce electricity costs for both generators and consumers (UNEP, 2008a). In the U.S., the world leader in installed geothermal capacity, enhanced geothermal systems can provide 100 gigawatts or 10% of the current electricity demand by 2050 (Tester et al., 2006). But reaching this goal will require $1 billion in funding for research and development, particularly to develop drilling techniques, power conversion technology, and reservoir development.

Renewable energies vary significantly with geographic location. Supply and demand often do not match very well; for example in China the best wind resources are in Inner Mongolia but the population is in coastal centers, such as Beijing-Tianjin. To get the energy from these new renewable sources to the consumer requires investments, both to develop and to deploy a grid backbone for clean energy commerce. Grid expansions can link clean energy resources with population centers, e.g. from CSP plants in Northern Africa to European cities or from wind generation plants in the U.S. Midwest to the more populated coasts. Large-scale inter-regional grid connection makes it easier to match supply and demand with renewable energies throughout the day (east-west connections) and year (north-south connections) (WBGU, 2003). To deal with natural fluctuations in the availability of renewable resources, particularly sun and wind, storage technologies will be required, such as melted sand for CSP plants and compressed air energy storage for wind generation. However, given the current mix of plants that can provide energy at the levels of base, intermediate, and peak loads, the grid can be made flexible enough so that wind energy can provide at least 20% of total energy at low grid integration costs (DeMeo et al., 2007). Hence, renewable energy can be expanded rapidly; it need not wait until better storage technologies become available.

Energy security would be a major benefit of a rapid switch towards a renewable energy mix. In fact, the European Union has been discussing the CSP-powered EU-MENA grid primarily in order to reduce its dependence on Russian fossil fuels. In fact, a group of European companies is pushing for the implementation of such an endeavor. In the U.S., becoming less dependent on Middle Eastern oil is a crucial motivation behind subsidies for agrofuels and the political pressure to provide electric and other more fuel-efficient cars.

Other grand-scale technology options are nuclear and carbon capture and storage (CCS). Nuclear energy is a mature technology and can be part of the future energy mix, though the cost of internalizing risks may reduce its financial viability. Crucially, other mostly renewable technologies and energy efficiency measures can be deployed on a sufficient scale to satisfy our future energy demand. It is important to foster research in CCS if we are to mitigate the emissions of existing coal plants in the future, especially in the U.S. and China. Doing so will require a strict and significant carbon price, along with high efficiency standards for power plants. Such a price will encourage the deployment of financially viable CCS. It is advisable to make the local externalities of coal, including air pollution and toxic landfills, an explicit part of an appropriate accounting.

SOLUTIONS FOR CITIES

With more than half the world's population now living in them, cities constitute a particular location where drastic reductions can be made in the energy needed for housing and transportation. Appropriate design of infrastructures and incentive schemes, along with technological innovation, can significantly reduce carbon emissions, and simultaneously improve the quality of life, e.g., by increasing accessibility and reducing air pollution. Given how important cities' scales and geographies are, it is worth focusing some of our energy efficiency discussion on them (Wilbanks, 2003).

Different aspects of cities' spatial dimensions provide insights into possible climate mitigation strategies. Carbon emissions and energy consumption are clearly a function of geographic circumstances. For example, in the U.S., January temperatures are negatively correlated with natural gas consumption and July temperatures are positively correlated with electricity consumption, reflecting heating and cooling needs respectively (Glaeser & Kahn, 2008). Other climate attributes, such as humidity, also contribute to the specificity of demands for energy.

Cities are never autonomous units; they rely on resources from their hinterland. In today's global economy, they also rely on resources from other continents, producing a global carbon footprint beyond their specific electricity and gasoline consumption. Indeed, in industrializing countries, much of the emissions stem from the production of goods for export to industrialized countries, but the reverse is not true (Suri & Chapman, 1998).

Cities also have their own spatial characteristics. Urban density is negatively correlated to gasoline consumption, and distance to the city center is positively correlated to it, indicating the negative impact that urban sprawl has on climate change. Dense Asian cities, and some European ones, perform better than U.S. cities that have fewer spatial constraints. Density is also related to the energy demand of buildings, one of the largest sources of GHG emissions. A city's form can also influence its micro-climate. For example, high levels of solar radiation from urban surfaces create urban heat-island effects, where the city temperature is significantly higher than that in the surrounding countryside.

These observations demonstrate that different cities face different energy needs and mitigation possibilities. According to its climatic region, a city may save energy by better and more appropriately regulating its heating and/or cooling systems, adapting them to factors such as the occupancy rates of office space and carefully avoiding overshoots in heating and cooling. With advanced smart control, millions of electricity-guzzling appliances, such as air conditioners and water heaters, can be fine-tuned and made to accommodate to rapid fluctuations in the renewable energy supply.

Dense cities can also reduce the GHG emissions in the transport sector by encouraging people to shift to public transportation; they can internalize the cost of auto transport by instituting city tolls and can implement low-cost but effective design measures to improve convenience and safety for pedestrians and bicycles. Crucially, the total social cost of car transportation in cities can exceed the climate costs by an order of magnitude. For example, in Beijing the costs and health consequences of congestion outweigh the climate costs by a factor of 15, as shown in Figure 2 (Creutzig & He, 2009).

Low-density cities face the syndrome of carbon lock-in, or the inability to develop low-carbon infrastructure due to adverse path-dependency. Still, ample opportunities exist to overcome this problem. For example, fuel efficiency measures and lighter vehicles can easily cut gasoline consumption in half; weatherization programs, such as insulating windows, can do the same for buildings. Convenient electric bicycles can satisfy a significant share of the need for transportation, and not only in Chinese cities. Innovative municipal instruments can

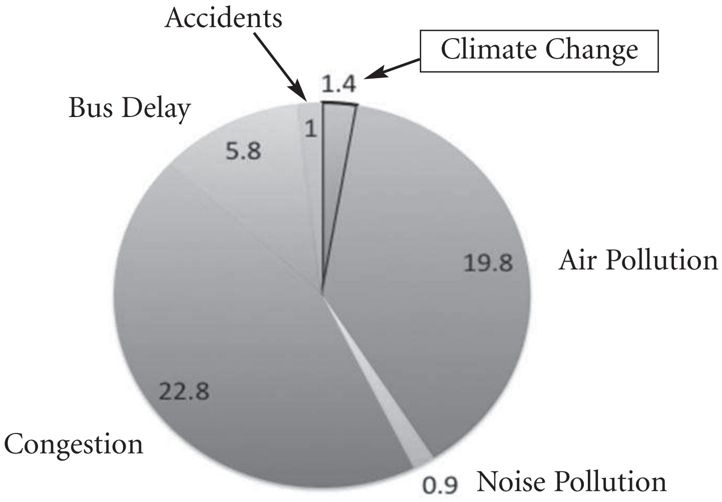

Figure 2. External costs of car transportation in Beijing. All values are in billions of RMB.

Source: Adapted from Creutzig & He, 2009.

successfully propel individual energy efficiency measures and increase the demand for decentralized renewable energy (Fuller, Portis, & Kammen, 2009).

At the same time, however, regulations and incentives should guarantee transit-oriented development and increase the housing density along public-transit corridors. We also need to redefine some concepts. For example, mobility should not be measured in miles travelled on concrete but in accessibility: how quickly can people access their work, stores, schools and hospitals? Accessibility can be improved by developing mixed-used neighborhoods that do not require highway construction. Even suburbs can be designed to facilitate car-free living when good streetcar connections are provided, as demonstrated by the Vauban quarter in Freiburg, Germany.

Finally, cities can be designed to adapt to their geographical location. Yazd, which lies in the Iranian desert, adapted to its climate by building wind towers that cool streets and houses with a refreshing breeze. Isfahan, another Iranian city located in an arid zone, has a historically well established water management system that can use scarce water resources for public gardens that cool the city. More generally, cool surfaces with a high albedo or reflectivity level, along with shade trees, can effectively mitigate both climate change and the urban heat island effect (Akbari, Pomerantz, & Taha, 2001). To go one step further, urban gardening can also help decrease resource dependencies and transportation costs. Many of these ideas are summarized in Table 1.

Approach	Location	Example	Co-Benefit
Fuel efficiency	Suburbs	Lighter materials & smaller cars	Cleaner air, energy security
Biofuels	-	Cellulosic waste, biomass cogeneration	Energy security
Transport Demand Management	Inner cities	Stockholm congestion charge	Faster, more reliable transport
Public transport	Inner cities	Beijing subway system	Mobility equality
Land-use research	Forests, food supply	Brazilian rain forest for soy production	Protection of biodiversity
Microgrids	Remote areas	Urambo, Tanzania	Reduction of energy poverty
Improved cooking ovens	Africa, India, China, Southeast Asia	Plant oil in Ghana	Improved respiratory health, decreased black carbon
Low-cost solar power	U.S., China, North Africa	Parabolic troughs in Andasol, Spain; PV on roofs	Energy security
Transmission	Across continents	DESERTEC	Facilitation of infrastructure
Smart grid	Buildings	Air conditioner control	Grid stability, jobs

Table 1. Potential solutions to global climate change: Locations, examples, co-benefits.

VISIBILITY AND MEASUREMENT: FROM GDP TO WEALTH ESTIMATION

The measures suggested above are motivated by a macro-economic perspective that considers social costs. But only if such a perspective becomes widely accepted will people fully embrace such measures. Here is where indicators can play a crucial role. Aggregate indicators are often used to judge government performance, so the choice of an indicator exerts considerable influence on the policy measures that politicians choose. The most notorious of all indicators is the gross domestic product (GDP). For more than 60 years, the GDP (or GNP) has been regarded as the single most dominant indicator of a nation's wellbeing. As a result, policy makers have focused on economic growth, or more precisely increased economic activity, arguing that other policy targets such as social stability would follow automatically. Though this argument has historically been justified by the high correlation of the GDP with more comprehensive measures of human well being, this logic collapses in eras like the present, with fundamental resource limitations and high global inequality.

GDP is an inappropriate measure for two reasons. First, it measures economic activity but not capital. Hence, a country's GDP could rise if economic forces are consuming the economy's capital, rather than reflecting productive wealth generation. Second, GDP only includes market goods, deliberately excluding human health, education, and—crucially— natural resources. A better index of well-being is wealth measured in accounting prices: the social value of resources and manufactured goods.[2] From this perspective, a society should strive to increase its wealth by producing positive genuine investment, i.e. increased wealth for its whole population. Genuine investments should also be used to evaluate policies, through a social-benefit analysis (Dasgupta, 2001).

In this framework, externalities are seen not as exemptions and deviations from the optimal market but as common features of real-world markets, particularly when natural resources are involved. Hence, markets function properly only if they can address externalities, an objective usually achieved by complementary regulations.

If we keep on measuring an economy predominantly in terms of its GDP, we may ignore the fact that its capital base is degrading quickly. In fact, the wealth of Sub-Saharan Africa has already degraded considerably in the last few decades (Arrow et al., 2004). Changing the accounting base will only slowly change consumption and production patterns. We must remember that the development and use of technology is path-dependent: as long as natural resources are underpriced, incentives favor the development of technologies that over-exploit them. Any change in the accounting base also has to overcome political barriers: owners and shareholders will not support change in accounting that do not favor their technologies. Also, customary habits of economic thinking are difficult to overcome. But the process of monitoring and measuring sustainability metrics and indicators can help as it both gauges and spurs sustainable development (Bossel, 1999; Meadows, 1998). Such a change in accounting would fit with a change in economic thinking which would then lead to changes in technology deployment that foster sustainability.

To make sustainable economics more visible and quantifiable, further research and actual on-the-ground deployment projects are needed in several methodologies for measurement and evaluation:

- We need a better methodology to determine the accounting prices for carbon stock, land uses, ecosystems, biodiversity, clean air, noise and other aspects of our environment. Accounting involves difficult issues such as the substitution of services, appropriate discounting over time, and the intrinsic value of biosystems. Further developing appropriate practices such as sensitivity analyses will make it possible to address the accompanying uncertainties. It would be helpful to make the process of dealing with soft, uncertain price estimation part of the economic curriculum.
- Ecosystem dynamics are usually nonlinear, so we need ways to understand the threshold values and catastrophic dynamics in more detail. Then, appropriate accounting prices can be adopted, or strict restrictions can be put in place if required.

- Research in behavioral and institutional economics is needed to determine which kinds of institutions can maximize wealth by handling natural resources properly.

How much weight can be given to indicators in general? How important is quantification? Quantitative science is needed to make decisions that are as informed as possible and can sharpen our intuition. But it is dangerous to rely only on those aspects that can be measured at a specific time and location. Often no data are available for a relevant set of measures, and other measures may be imperfect. Hence, only a small set of measures is left that is judged to be suitable—leading researchers, politicians and citizens to make the problematic assumption that a part truly represents the whole. This situation is aggravated by gaming behavior, in which managers act only to meet a specific target and underperform on important other tasks (Bevan & Hood, 2006). Hence, even a varied set of indicators should not be an all-exclusive measure of government performance. Instead, decision-makers must take a holistic view even when they are lacking some relevant data.

When decision-makers gain more information about ecosystem dynamics and social accounting, they can design economic institutions to foster sustainability. Fundamentally, this means that macroeconomics must shift to become a more empirical science. Also, just as economists systematically embrace ecological studies that involve a natural resource base, ecologists must investigate the impact that economic institutions have on ecosystems. Hence, from our point of view, both disciplines converge in an apparent reflection of their ethymologicy: the laws (*nomoi*) that we use to manage our global household (*oikos*) are based on its fundamental order (*logos*).

CARBON DIVESTMENT AND SCALING UP GREEN AID

What does this sustainable development framework imply for investment, particularly for multilateral investment banks? It is clear that investment strategies and decisions play a crucial role in a transition toward low-carbon technologies for energy production. Multilateral development banks (MDBs) play a crucial role as they have significant budgets and can function as cheerleaders for other banks and donor agencies.

An important question here is how much aid goes into *green* projects. Between 1980 and 1999, both bilateral and multilateral agencies significantly increased green aid and reduced the ratio of dirty to green aid. However, bilateral agencies perform better: they decreased their ratio of dirty to green aid from factor 10 to factor 3, i.e. bilateral agencies now only fund three times as many dirty projects (coal etc.) as 'green' projects. Multilateral agencies are slightly worse as they went from factor 10 to factor 4 and did not improve their spending ratio from 1992 onwards. Moreover, huge differences exist among the multilateral agencies. For example, the EU has increased green aid by 600% and the World Bank by 89% (Hicks, Parks, Roberts & Tierney, 2008). The World Bank is crucial as it is responsible for one third of all aid from multilateral banks and is considered to be a trustworthy first-mover, in many cases leveraging additional funds from other banks. This is important as multilateral banks, on average, have not reduced their dirty aid since 1999.

According to Friends of the Earth, in recent years the World Bank has increased its funding for oil, coal and gas projects. Like the World Bank, the European Investment Bank invested more than $3 billion into fossil-fuel related projects in 2007 (Lyman, 2008). In 2008, the World Bank approved a $450 million loan for a massive 4,000 megawatt coal project in India, expected to emit more emissions than some entire countries. By this measure, the World Bank was also leveraging more than $4 billion in overall funding. The Bank also plans to finance a coal-fired project in Mmamabula, Botswana. A reasonable shadow price for carbon would make this project less attractive and other technologies such as concentrated solar power (CSP) would become more competitive (Wheeler, 2008).[3] Central power plants also tend to increase energy inequality when rural areas cannot get access to a grid. Hence, a mix of a medium-sized CSP plant and seed funding for a market for microgrids is in many cases more appropriate.

The investment portfolios of MDBs can be made more sustainable. For example, accounting practice still regards environmental assessment as an add-on, rather than an integral part of project evaluation.[4] We suggest that donor governments withhold World Bank funds until it changes its incentives for personal advancement and its accounting practices. The bank should also establish carbon shadow prices for all its projects and explicitly evaluate land-use changes, e.g., through logging. It could consider a complete ban on fossil fuel projects, a step suggested in the Bank's own 2004 Extractive Industries Review. Also, personal advancement in development banks is sometimes based on the size and revenue flow of the funds an employee manages, thus promoting large-scale projects that are usually less sustainable. Internal career incentives could be structured around sustainability indicators.

Of course, divestment of carbon-producing systems is also required within OECD countries. For example, at present, Germany annually adds seven coal power plants, totaling about 8500 MW or 7% of current installed capacity. Investments in sustainable technologies do not mitigate climate change if dirty technologies continue to receive large-scale financing. Moreover, governments continue to subsidize the use of fossil fuels and need to rethink their policies to tackle climate change (UNEP, 2008b). OECD countries must also rethink their overseas development aid (ODA). Thus far, they are only providing 4% of the aid to mitigate climate change that they promised in 1992 at the Rio conference, and their total green aid is only 15% of what they promised (Hicks et al., 2008). These observations call for efforts to scale up green aid by a factor of ten. Some funding can come from scrapping dirty aid projects, but overall the aid must be doubled. It is crucial that projects integrate the needs of local communities and contribute to sustainable development—complementing the CDM where it fails to live up to its potential.

CLEAN ENERGY TECHNOLOGIES: NEEDED AND VALUABLE

Innovation is the main driver for new infrastructures and employment, but what drives innovation? Because it is a public good, governments must play a role in funding basic research to answer this question. Robert Solow (1957), the Economics Nobel laureate, estimated that over 90% of new economic growth results from public and private sector investments in innovation. A range of estimates using diverse methods from other researchers and government agencies supports this finding. While investment in research and development is roughly 3% of the U.S. GDP, it is roughly *one-tenth* of that in the energy sector. Careful funding of research is crucial to leverage high returns in terms of renewable energy deployment. For example, the market for CSP does not contain much room for investments into technology innovation, but moderate amounts of funding for research could help move CSP along the endogenous learning curve. The new U.S. administration has already indicated that it intends to increase R&D funding in energy research by a factor of ten, to $15 billion. Countries that seek to participate in future lucrative sustainable energy technology (SET) markets can follow suit. Above, in the section on technology options and cities, we pointed out specific areas of suggested research. But equally crucial research must go beyond specific energy generation or efficiency gains, for example considering appropriate demand management and ways to optimize infrastructure.

Government banks and development banks should also provide liquidity for large-scale wind and CSP projects and reduce the barrier created by high front-up costs. A boom in renewable energy projects can provide an urgently needed boost for job markets. Three to five times as many jobs were created when an investment was made in renewable energy compared to a similar one in fossil-fuel energy systems (Kammen, Kapadia, & Fripp, 2004; Kammen, 2007; Engel and Kammen, 2009). Furthermore, government and donor banks can take the risk of investing in uncertain projects, like geothermal exploration.

INSTITUTIONAL INTEGRATION IN AGENCIES AND IN THE BALI PROCESS

To utilize the wider economics and political opportunities of the co-benefits of climate protection with the direct message of climate risks will require a multi-sectoral dialog and set of metrics. Up to now, climate change policies have largely been a matter for environmental ministries that have had little authority over energy, housing, transportation, and commercial activities. This is a natural beginning, but in the long term it is not enough to design a few, or even many, well-structured programs. To confront climate change and to design a more sustainable energy system will require developing a set of goals, along with objectives for the public and private sectors; then they must be articulated, and applied fairly across the economy. Special attention must be paid to the situation of poor and disadvantaged communities (in *both* industrialized and industrializing nations), and to ways to encourage and disseminate innovative clean energy technologies, practices, and accords. Such a policy framework ideally would address basic research and the dissemination and diffusion of technology, and must include the energy and climate decisions made both by households and communities, and by national and international institutions.

What implications does our perspective have for an international climate regime?

Let us take the transportation sector and avoided deforestation as examples. The transportation sector has the fastest-growing GHG emissions, but has been widely ignored in the international climate regime. Investments and programs for mitigating its contribution to climate change have been disappointing, across both institutions and countries. For example, only 0.1% to 0.2% of all Certified Emission Reductions of CDM are attributed to transportation. The most important contribution to mitigation in the transport sector has been through unreported actions in developing countries. The current CDM framework focuses on single-source, context-detached, quantifiable, and technology-oriented measures, but for the transportation sector this approach entails high transaction costs and tough verification obstacles. However, if a system takes an Avoid-Shift-Improve approach to urban transport, that could lead to significant reductions in GHG emissions and huge co-benefits (Huizenga, Dalkmann, & Sanchez, 2009). In such a paradigm, future emissions are avoided as improved accessibility and better integration of transport and land-use planning reduce the need for travel. Thus travel is shifted to sustainable modes and both the transport systems and vehicles become more efficient.

For example, a city toll for Beijing (a la the congestion pricing in London), along with a synergetic expansion in bus rapid transit and non-motorized transport has been estimated to produce more than 10 billion RMB annually in co-benefits (Creutzig & He, 2009). Barriers to implementation often remain when no one measures the co-benefits and institutional segregation (Creutzig, Thomas, Kammen, & Deakin, 2009). An ideal way to support cities in non-Annex-I countries is a sectoral approach, such as sectoral crediting, that rewards successful measures to manage transportation demands.

In the area of avoiding deforestation, we suggest a combined effort by behavioral and institutional economists, biologists, ecologists and anthropologists, along with local, national and supranational stakeholders. Together they can design institutions that can successfully protect the forests. Instruments and institutions are appropriate if they follow five principles: environmental effectiveness, economic efficiency, distributional fairness, political feasibility and robustness against gaming and manipulation. The last requirement—robustness—is only instrumental with respect to the others but it is important to avoid outcomes like the current European trading scheme or the CDM scheme. As these schemes show, a design focused on market efficiency easily leads the market participants to engage in gaming behavior and vested financial interests can access it too easily. In particular, a purely monetary reward can crowd out community resource management regimes. To avoid deforestation and to preserve and enhance sustainable community management, we must focus on capacity building and land-use taxation and slowly phase in certificate trading in order to avoid compromising environmental effectiveness and the robustness needed for economic efficiency.

Two actions will make the future climate regime more acceptable and politically feasible: implement it in a variety of local contexts and relate mitigation measures to co-benefits. These actions are crucial if we are to make the change to a sustainable economy.

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Endnotes

1 www.desertec.org
2 An inclusive notion of human well-being would also consider civil and political liberties.
3 Note that the cost assumptions of this study can be disputed.
4 A standard argument is that more thorough accounting would be too complicated as it would increase transaction costs. However, an order-of-magnitude estimation of carbon emissions from a coal power plant can be done in a few minutes.

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