COBENEFITS AND TRADE-OFFS OF GREEN AND CLEAN ENERGY: EVIDENCE FROM THE ACADEMIC LITERATURE AND ASIAN CASE STUDIES

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1. In this publication, "$" refers to US dollars.
2. ADB recognizes "China" as the People's Republic of China.
3. Corrigenda to ADB publications may be found at http://www.adb.org/publications/corrigenda

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ABSTRACT

This working paper assesses the positive cobenefits of promoting green and clean energy in Asia. It first defines what is meant by “clean” energy across the four technological systems of cooking, renewable electricity, energy efficiency, and urban transport. Then, drawn from a synthesis of peer-reviewed articles, it summarizes at least four general types of cobenefits of investing in these systems: (i) diversification and enhanced energy security, (ii) jobs and green growth, (iii) displaced pollution and associated cost savings, and (iv) enhanced resilience and adaptive capacity to things like climate change and natural disasters. It also offers some insight to possible challenges and trade-offs that must be managed when attempting to capture cobenefits. The paper then focuses on four case studies of cobenefits that have been delivered in practice: liquefied petroleum gas stoves in Indonesia, renewable electricity generation in the People’s Republic of China, energy efficiency in Japan, and mass transit in Singapore. The paper concludes with insights for energy analysts and policy makers.

Keywords: climate change

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I. INTRODUCTION

Asian countries have made remarkable efforts at increasing their electrification rate, yet energy access oscillates noticeably. The People's Republic of China (PRC) alone accounts for about 30% of the electricity generated for the entire region, and six countries—Australia, the PRC, India, Japan, the Republic of Korea, and the Russian Federation—account for 87% of generated electricity. When analyzed as per capita figures, houses in New Zealand or Australia consume 100 times more electricity than those in Bangladesh and Myanmar. The region is also home to small island developing states like Fiji and Vanuatu that are extremely difficult to supply with modern energy services. These countries, heavily dependent on diesel imports with exceptionally small electricity grids and low levels of affordable access, are spread across about a third of the earth's surface but are home to less than a thousandth of the world's population. What sorts of energy technologies can provide access and address these concerns? Moreover, what case studies of success exist for Asian countries to learn from?

To provide some answers, this working paper assesses the positive cobenefits of promoting green and clean energy in Asia. It first defines what is meant by "clean" energy across the four technological systems of cooking, renewable electricity, energy efficiency, and urban transport. Then, drawn from a synthesis of peer-reviewed articles, it summarizes at least four cobenefits—defined as positive, social, or economic spillovers that occur in addition to merely the provision of energy—to investing in these types of systems. These include (i) diversification and enhanced energy security, (ii) jobs and green growth, (iii) displaced pollution and associated cost savings, and (iv) enhanced resilience and adaptive capacity to things like climate change and natural disasters. The paper also offers some insight into possible challenges and trade-offs that must be managed when attempting to capture cobenefits. The paper then focuses on four case studies of cobenefits delivered in practice: liquefied petroleum gas stoves in Indonesia, renewable electricity generation in the PRC, energy efficiency in Japan, and mass transit in Singapore. Table 1 offers an overview of the historical period, a description, and results of these cases. The paper concludes with insights for energy analysts and policy makers.

Table 1: Programmatic Summary of Exemplary Asian Case Studies

Topic Area	Case Study	Period	Description	Key Cobenefit(s)	Results	Challenges
Cooking	Indonesia	2007–2012	Under the leadership of Vice-President Jusuf Kalla, the Indonesian LPG Megaproject offered households the right to receive a free "initial package" consisting of a 3-kilogram LPG cylinder, a first free gas fill, one burner stove, a hose, and a regulator. The government, in tandem, also started repealing kerosene subsidies (increasing its price) and constructing new refrigerated LPG terminals to act as national distribution hubs.	Health, rural poverty reduction, jobs	In just 3 years—from 2007 to 2009—the number of LPG stoves nationwide jumped from a mere 3 million to 43.3 million, meaning they served almost two-thirds of Indonesia's 65 million households. Six entire provinces, including Jakarta, the capital, have also been declared "closed and dry," meaning that every single household reported receiving a package and that all kerosene subsidies have been withdrawn.	Social acceptance of users, subsidy reform, comparative but not absolute emissions reductions
Renewable electricity	People's Republic of China (PRC)	1988–2015	The Twelfth Five-Year Plan (FYP), adopted by the PRC government in March 2011, has continued the country's support for renewable energy and further brought environmental and climate-oriented concerns to the forefront of national policy. New renewable energy production has been driven by the emergence of carbon trading platforms and international treaties such as the Kyoto Protocol.	Pollution abatement, mitigation of greenhouse gas emissions, diversification	The PRC leads the world in the largest amount of renewable energy capacity installed, and it ranks first in multiple categories of renewable energy. It is home to approximately a fifth of the world's renewable power capacity. In 2012, power generation from renewables increased more than generation from coal and surpassed and exceeded the output of nuclear power plants.	Energy scramble and fossil fuels, interconnection and affordability issues
Energy efficiency	Japan	1999–2012	The "Top Runner" program sets energy efficiency standards for 19 different products and within a time period mandated by the government requires efficiency performance to improve across covered products. The program's goals are also strengthened by "naming and shaming" companies that do not comply.	Technological innovation and performance	Product savings have reached as high as a 67.8% improvement for air conditioners, 78% for fluorescent lights, and 99.1% for computers over time. The program is expected to deliver $3 billion in benefits in markets for lighting, vehicles, and appliances.	Industry resistance, risk of rebound effects and leakage, unique cultural element of shaming
Urban transport	Singapore	1971–2009	Restrained private automobile ownership through vehicle moratoriums and fees, levied congestion charges for roads and expressways during peak times, and vigorously promoted bus and rail mass transit.	Reduction of congestion, generation of tax revenue	Almost two-thirds of daily trips during peak hours occur on mass transit, more than 95% of roads and expressways are congestion free, and road pricing scheme funnels $138 million in fees back into the government budget.	Aspirations to still own a car, requires fairly heavy-handed state intervention, capital intensive, still privileges motorized transport

LPG = liquefied petroleum gas.
Source: Compiled by the author.

II. CONCEPTUALIZING FOUR GREEN AND CLEAN TECHNOLOGIES

The paper begins by laying out its assumptions of what it considers "green" or "clean" technologies, providing definitions for clean or improved cookstoves, renewable electricity, energy efficiency, and low-carbon urban transport.

A. Clean and Improved Cookstoves

The potential for cleaner and improved forms of cooking is truly gargantuan, with roughly 2.7 billion new customers for cooking fuels and technologies entering the marketplace (38% of the global population) (IEA 2015). Though the term "improved" is subjective, modern stoves take a variety of forms. Sanchez (2010) argues that an "improved" cooking source is one that requires less than 4-person hours per week per household to collect fuel, has a conversion efficiency above 25%, and meets World Health Organization guidelines for air quality. Improved or clean stoves therefore frequently require a switch away from charcoal or polluted wood to "healthier" fuels such as soft biomass, crop residues, and firewood; they have a grate and an improved combustion chamber; and they almost always have a chimney. They utilize higher temperature ceramics, fire-resistant material, longer-lasting metals, and possess more insulation and a better frame that guides hot gases closer to cooking pots. They can cook more food at once and many have coils around the combustion chamber to heat water while cooking is in process. Some improved stoves are connected to radiators or space heaters so that heat could be recycled and/or vented to other rooms, and some stoves send heat through pipes directly into a brick platform that occupants sleep on at night (Brown and Sovacool 2011).

B. Renewable Electricity

Renewable electricity is dependent on nondepletable fuels that can be utilized through a variety of sources, approaches, systems, and technologies; in each case, renewing at a rate faster than they are consumed.[1] Plants and algae can capture sunlight for photosynthesis before they convert it to biofuels or biopower. Hydropower capitalizes on the rain and snowfall resulting from water evaporation and transpiration. Wind generates electricity directly by turning a turbine or indirectly in the form of ocean waves, but the wind itself is driven by the sun. Tides go up and down due to the gravitational attraction between the oceans and the moon. The heat trapped in the earth itself can be put to productive use through geothermal applications.

Operators and analysts generally categorize electricity systems according to their fuel sources, as shown in Table 2: wind turbines (onshore and offshore); solar energy (including solar photovoltaic panels, solar thermal systems, and concentrated solar power); geothermal (conventional and advanced); biomass (including landfill gas, agricultural waste, refuse, energy crops, as well as biofuels such as ethanol and biodiesel); hydroelectricity (large and small); and ocean power.

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[1] While often characterized as relying on renewal through natural processes, some renewables in fact can rely upon or be enhanced by human assistance to natural processes. An example would be multi-species reforestation to offset a wood-fired electricity generating system.

Table 2: Renewable Electricity Technologies and Associated Fuel Cycles

Source	Description	Fuel
Onshore wind	Wind turbines capture the kinetic energy of the air and convert it into electricity via a turbine and generator.	Wind
Offshore wind	Offshore wind turbines operate in the same manner as onshore systems but are moored or stabilized to the ocean floor.	Wind
Solar photovoltaic (PV)	Solar photovoltaic cells convert sunlight into electrical energy through the use of semiconductor wafers.	Sunlight
Solar thermal	Solar thermal systems use mirrors and other reflective surfaces to concentrate solar radiation, utilizing the resulting high temperatures to produce steam that directly powers a turbine The three most common generation technologies are parabolic troughs, power towers, and dish-engine systems.	Sunlight
Geothermal (conventional)	An electrical-grade geothermal system is one that can generate electricity by means of driving a turbine with geothermal fluids heated by the earth's crust.	Hydrothermal fluids heated by the earth's crust
Geothermal (ad-vanced)	Deep geothermal generators utilize engineered reservoirs that have been created to extract heat from water while it comes into contact with hot rock and returns to the surface through production wells.	Hydrothermal fluids heated by the earth's crust
Biomass (combustion)	Biomass generators combust to biological material to produce electricity, sometimes gasifying it prior to combustion to increase efficiency	Agricultural residues, wood chips, forest waste, and energy crops
Biomass (digestion)	Biomass plants generate electricity from landfill gas and anaerobic digestion.	Municipal and industrial wastes and trash
Biomass (biofuels)	Liquid fuels manufactured from various feedstocks	Corn, sugarcane, vegetable oil, and other cellulosic material
Hydroelectric	Hydroelectric dams impede the flow of water and regulate its flow to generation electricity.	Water
Ocean power	Ocean, tidal, wave, and thermal power systems utilize the movement of ocean currents and heat of ocean waters to produce electricity.	Saline water

Source: Modified from Sovacool, Benjamin K. 2008. *The Dirty Energy Dilemma.* Westport, CT: Praegar.

C. Energy Efficiency

Energy efficiency refers to the long-term reduction in electricity consumption as a result of the increased deployment or improved performance of energy-efficient equipment (Brown, Southworth, and Stovall 2005). By reducing electricity consumption, energy efficiency is a low-cost contributor to system adequacy—the ability of the electric system to supply the aggregate energy demand at all times—because it reduces the baseload as well as the peak power demand. This reduction in peak power requirements can also contribute to system security—the ability of the system to withstand sudden disturbances—by reducing the load and stress at various points in the power distribution system, thereby decreasing the likelihood of failures. As one influential report on efficiency put it, "… energy-efficiency opportunities are typically physical, long-lasting changes to buildings and equipment that result in decreased energy use while maintaining constant levels of energy service" (Rufo and Coito 2002, 1-1).

A close corollary of energy efficiency, demand side management, refers to programs that allow utilities to better match their demand with their generating capacity. By changing the load curve for utilities, system reliability can be enhanced and new power plant construction can be avoided or delayed. Current programs tend to aim at limiting peak electricity loads, shifting peak loads to off-peak hours, or encouraging consumers to change demand in response to changes in the utilities' cost of providing power (Gillingham, Newell, and Palmer 2004).

Another variant is demand response, which refers to curtailment or other immediate steps that are aimed at reducing the peak megawattage of load (Brown and Sovacool 2008). Real-time demand–response programs allow consumers to respond to electricity prices directly, offering mechanisms to help manage the electricity load in times of peak electricity demand to improve market efficiency, increase reliability, and relieve grid congestion. Significant consumer benefits also accrue from real-time demand–response programs, chiefly in the form of cost savings because of lower peak electricity prices, less opportunity for market manipulation by electricity providers, and additional financial incentives to induce their participation in these programs (Goldman et al. 2005).

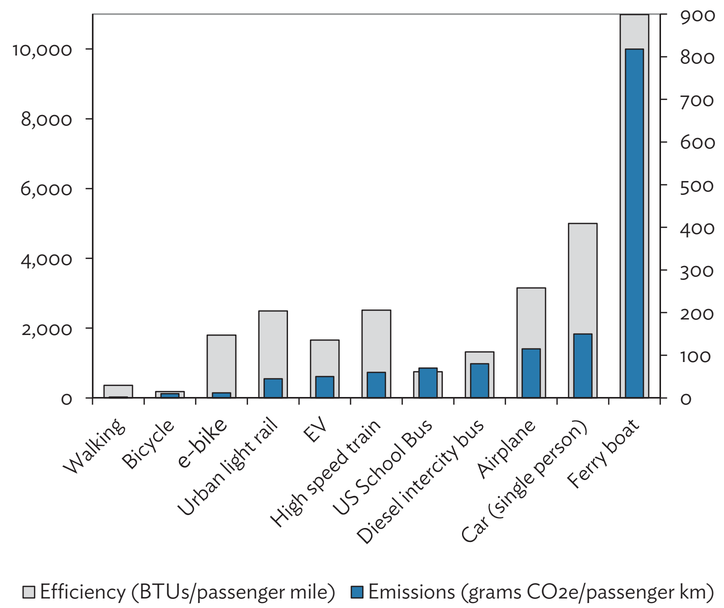
D. Low-Carbon Transit and Mobility

Due to its complexity, transport planners generally argue that "low-carbon" or "sustainable" involves one of four tracks (Woodcock et al. 2007): One is improving the energy efficiency of transport modes and technologies, either through accelerated innovation or radical component substitution (e.g., hybrid electric vehicles, fuel cell vehicles, and biofuel for transport). Some of this can focus on existing technologies rather than entirely new or novel ones. Although most major automobile manufacturers have released electric vehicles (EVs), they also market an array of increasingly fuel-efficient models propelled by blended fuels or hybrid technology. Given the difficulty of transforming infrastructure systems, EV critics argue that similar carbon dioxide (CO_2) reductions can be gained by improving conventional internal combustion engine (ICE) technology and shifting to flex fuels. A number of emerging technologies are expected to significantly improve ICE vehicle efficiency over the next 2 decades (Bandivadekar et al. 2008). In addition, reductions in vehicle weight, improved aerodynamics, and size decreases could improve fuel efficiency. It has been estimated that a 20% vehicle weight reduction in an average vehicle is possible over the next 25 years, producing a further 12%–20% reduction in fuel consumption.

A second is reducing car use through a modal shift, especially to things like "active transport" and bicycling. Active transport holds significant potential to both improve health and lower transport-energy use. Advocates of a new transport paradigm suggest that far better transport strategies exist, ones that promote human fitness and better transport efficiency, and include a mix of walking, cycling, and public buses and trains. Figure 1 quantifies the enhanced transport efficiencies and reduced emissions associated with various modes of transport including walking, cycling, electronic bikes, and light rail.

Another is reducing trip lengths through (nontransport) innovations such as compact cities and smart cities. These studies suggest that urban form and infrastructure is key to transport sustainability. Higher-density land use is inherently more energy-efficient because distances are shorter. Combined with developments in public transport, higher density enables a more frequent and higher-occupancy public transport with lower emissions per passenger. Mixed-use developments, better housing location and building design, and support for local services that can reduce travel distances to employment, education, health services, and shops are all part of this strategy (Woodcock et al. 2007).

Figure 1: Energy and Carbon Intensity of Transportation Modes



BTU = British thermal unit, CO_2e = carbon dioxide equivalent, EV = electric vehicle, km = kilometer, US = United States.
Source: Modified from Cleveland, Cutler J., and Christopher G. Morris, eds. 2013. *Handbook of Energy Volume I: Diagrams, Charts, and Tables.* London: Elsevier Science.

A final track is reducing the need to "travel" through innovations such as teleworking and internet shopping. Such studies tend to suggest that avoiding vehicle trips can be met through things like information and communication technology (e.g., teleconferencing) that can replace physical travel with electronic communication.

III. ACADEMIC LITERATURE ON COBENEFITS AND TRADE-OFFS

The four technologies—cleaner cooking stoves, renewable electricity, efficiency, and transport—not only provide energy or mobility, but also have an array of "cobenefits." This refers to the positive side effects, secondary benefits, collateral benefits, or associated benefits from a particular green policy or clean energy system (Miyatsuka and Zusman 2010). Cobenefits can be direct or indirect, as well as monetary or nonmonetary. A useful classification of cobenefits is provided by the Asian Development Bank (ADB and ADBI 2013, chapter 4), which notes that "Level 1" cobenefits can refer to circumstances where cobenefits are roughly proportional to the amount of investment, such as jobs or improvements to health. "Level 2" cobenefits are more abstract and need not always be tied to the scale of investment, but are required to reach a particular level, such as achieving energy security or independence from particular imports. "Level 3" cobenefits can refer to multiplier benefits that are interlinked with many causal factors and are not easy to quantify, such as enhancements to national competitiveness or innovation.

Despite these differing levels and types of cobenefits, the idea is that investments in clean and green energy produce benefits beyond the energy system and can include reductions in emissions, cost savings, jobs, improvements to health, and a reduced risk of climate change (Reinhardt 1999). As President of the United States Barack Obama put it, "a transition to clean energy is good for business" (Lewis 2014). Similarly, World Bank Group President Jim Yong Kim argues that there is no trade-off when it comes to transitioning to clean technology: "we believe it's possible to reduce emissions and deliver jobs and economic opportunity, while also cutting health care and energy costs."[2] Although the cobenefits offered by clean energy systems are diverse and difficult to value and monetize, we briefly survey them across four categories: energy security, green growth, environmental pollution such as climate change and the degradation of air quality, and resilience. Cobenefits also have some complexities discussed in section III.E. To be sure, these cobenefits are not the only ones; others that may deserve exploration in future research include:

- preservation of land use and wildlife,
- fuel availability and/or stability and predictability of prices,
- energy payback ratios or energy returns on investment
- modularity and quicker construction times,
- learning curves and rates of improvement,
- enhanced reliability and the avoidance of blackouts,
- minimal water consumption or usage,
- mitigation of hazardous on-site accidents, and
- reductions in poverty or empowerment of vulnerable groups.

A. Diversification and Energy Security

One benefit to clean energy is diversification away from conventional fossil fuels or incumbent infrastructure systems. This diversification can encompass at least three dimensions (Sovacool 2010): Source diversification requires utilizing a mix of different energy sources, fuels, types, and fuel cycles (i.e., relying not just on nuclear power or natural gas but also coal, oil, wind, biomass, geothermal, etc.). Supplier diversification refers to developing multiple points of energy production so that no single company or provider has control over the market (i.e., purchasing natural gas from not just one or two companies but a diversified mix of dozens of energy firms). Spatial diversification means spreading out the locations of individual facilities so that they are not disrupted by single attack, event, malfunction, or failure (i.e., spreading refineries across the country instead of placing all of them along the same coast). Typically, an "optimized" level of diversification is achieved when all three dimensions are promoted at once, or certain portfolios of energy systems are arranged to explicitly minimize risk across the entire sector at the lowest cost. For instance, many renewable electricity systems can bring multiple, positive cobenefits, ranging from hedging against fossil fuel price volatility and reduced greenhouse gas (GHG) emissions to improved stakeholder relations and the revitalization of rural areas, as Table 3 indicates (Pater 2006).

Indeed, many studies have suggested that a diversified energy mix encourages technological competition between energy platforms, ensuring that progressive innovation takes place and that costs are minimized (Helm 2002). A diverse portfolio of technologies also helps attenuate load imbalances caused by stochastic power flows and ensures that unexpected increases in factor prices associated with any given technology do not significantly impact the economics of the entire energy system (Valentine 2011). Portfolio diversification allows nations to weather unexpected disruptions to energy

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[2] Quoted in Suzuki (2014).

supply whether it is caused by economic shocks, natural disasters, terrorism, or geopolitical developments (Sovacool and Mukherjee 2011). A diversity of technologies allows different regions of a nation to exploit any geographic or technical competencies by supporting renewable energy technologies that fit the community context (Awerbuch 2006). Spreading out the supply of energy across a number of technological platforms minimizes the damage that can be caused by sole reliance on one technology that for whatever reason suffers a competitive or technological setback (Li 2005). Japan's nuclear power program comes to mind in this regard.

Table 3: Positive Cobenefits to Renewable Sources of Electricity

Risk Management	Environmental Performance	Investment	Reduced Resource Use	Improved Public Image	Economic Spillover Benefits
Hedge against fuel price volatility	Emissions credits	Production tax credit	Reduced water use	Improved relations with stakeholders	Rural revitalization
Hedge against future environmental regulations	Reduced emissions fees	Accelerated depreciation	Lower production costs	Corporate social responsibility	Jobs and employment
Hedge against future carbon tax	Avoided remediation and pollution abatement costs	Local tax base improvements	Reduced energy use and wear and tear on transmission and distribution grid		Economic development
Minimization of reliance on futures markets					Avoided environmental costs of fuel extraction and transport
Reduced insurance premiums					

Source: Pater, J. E. 2006. *A Framework for Evaluating the Total Value Proposition of Clean Energy Technologies*. Technical Report NREL/TP-620-38597, February. Golden, CO: National Renewable Energy Laboratory.

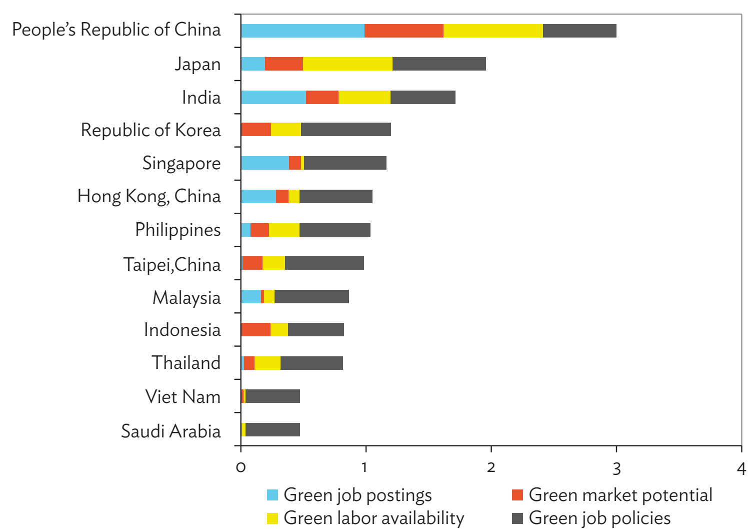
B. Jobs and Green Growth

A second cobenefit is perhaps more straightforward and easier to measure—jobs and green growth—though most of the literature focuses on countries in Europe or the United States.

The more capital intensive an energy technology or infrastructure system is, the less embodied labor it has. Nuclear power and fossil-derived electricity are the most capital intense and create net reductions in regional employment as ratepayers must reduce expenditures on other goods and services to finance construction. Renewable energy technologies such as wind and solar as well as distributed sources of energy such as efficiency, however, generate 3–10 times as many jobs per megawatt of installed capacity as fossil fuel—or nuclear-based generation (UNEP 2000; Kammen, Kapadia, and Fripp 2004). Renewable power sources also contribute to local economic growth and, according to some, provide *better* jobs. The manufacturing of renewable power technologies involves a highly skilled workforce and a modernizing of the local industry base. The use of renewable energy makes local businesses less dependent on imports from other regions, frees up capital for investments outside the energy sector, and serves as an important financial hedge against future energy price spikes. In some regions of the United States, such as the Southeast, electric utilities expend $8.4 billion per year importing the coal and uranium needed to fuel conventional power plants. Investments in those power plants send money *out* of the economy whereas investments in renewable power keep money *in* the economy. About 50 cents for every dollar expended on conventional electricity leaves the local economy (and in some areas 80%–95% of the cost of energy leaves local economies), whereas every dollar invested in renewable electricity can produce $1.40 of gross economic gain.[3]

Studies of the employment effects of specific mitigation measures in Asian countries seem to validate many of these findings, and have also illustrated a substantial scope for more green job creation across not only renewable energy and energy efficiency but also agriculture and forestry activities as well as green transport and public works. Overall, ADB and ADBI (2013) estimate that the potential gross green job creation in Asia is significant, on average at least of the order of 1% or 2% of the labor force. In addition, the potential for green jobs tends to be larger in poorer Asian countries because of the greater need to improve the environment and because of higher unemployment rates. Figure 2, for instance, depicts the green jobs potential across many major Asian economies.

Figure 2: Green Jobs Potential of Selected Asian Economies



Source: Asian Development Bank and Asian Development Bank Institute. 2013. *Low-Carbon Green Growth in Asia: Policies and Practices*. Manila: ADB.

Similarly, investments in energy efficiency have been shown to enhance industrial competitiveness, generate economic returns, and displace emissions at the same time (Niederberger et al. 2005). The National Research Council reviewed 17 major energy efficiency programs funded by the United States Department of Energy from 1978 to 2000, covering residential energy consumption efficiency such as the development of advanced refrigerators or compact fluorescent lights, commercial improvements such as electronic ballasts, and industrial improvements such as oxygen-fueled glass furnaces and lost foam casting for steel making (Committee on Benefits of DOE R&D on Energy Efficiency and Fossil Energy et al. 2001). They estimated that the total net realized economic savings from these programs amounted to $30 billion (in 1999 dollars), while the programs cost only

3 These figures come from two studies in California and Arizona, along with a survey conducted by Lovins and Lovins (1982, 306). See Stoddard, Abiecunas, and O'Connell (2006) and Arizona Department of Commerce Energy Office (2004).

$7 billion in total to fund. Another assessment of the Warm Front scheme in the United Kingdom, which provided energy audits and grants for low-income housing investments in energy efficiency, concluded that over its lifetime the scheme cost £2.4 billion but will yield £87.2 billion in savings (Sovacool 2013).

There is also substantial evidence that energy efficiency is the best way to mitigate GHG emissions while also meeting the growing requirements for energy services that accompany expanding economic growth (Brown and Sovacool 2011). A comprehensive report from the independent consulting firm McKinsey & Company (2010) concluded that a host of residential and industrial energy efficiency options were far more cost effective than building power plants, even those running on natural gas or renewable fuels. For the United States, McKinsey (2009, 12) calculated that:

> A holistic approach would yield gross energy savings worth more than $1.2 trillion, well above the $520 billion needed through 2020 for upfront investment in efficiency measures (not including program costs). Such a program is estimated to reduce end-use energy consumption in 2020 by 9.1 quadrillion BTUs, roughly 23 percent of projected demand, potentially abating up to 1.1 gigatons of greenhouse gases annually.

Similarly, one peer-reviewed evaluation of the Energy Star program in the United States determined that from 1992 to 2006, it saved 4.8 exajoules of primary energy, circumvented 82 million tons of carbon-equivalent emissions, and would subsequently prevent a further 203 million tons of emissions from 2007 to 2015 (Sanchez et al. 2008). A separate study examined the cumulative primary energy savings from the Energy Star program and determined that it would save $70 billion worth of cumulative energy over that decade, even though managing the program cost only a small fraction of that amount (Brown, Webber, and Koomey 2002).

Advocates further argue that investments in efficiency tend to generate opportunities in industries such as construction that are more labor intensive than average, meaning they produce more net jobs per dollar invested (ACEEE 2011). One study conducted by the American Council for an Energy-Efficient Economy, a pro-efficiency think tank, calculated that investments in efficiency from 1992 to 2010 would generate 1.1 million net jobs compared to business as usual (Geller, DeCicco, and Laitner 1992). The International Energy Agency found that consumers and businesses “respend” their energy bill savings from efficiency improvements in areas of the economy that are more labor intensive and productive than energy purchases. They calculated that reducing energy consumption by 15% during 1995–2010 resulted in 770,000 additional jobs, equivalent to a 0.44% increase in overall employment rate, and $14 billion in additional wages and salary incomes per year (Geller and Attali 2005). California’s comparative advantage in energy efficiency, for instance, generated about $56 billion in net economic benefits since 1972, yielding an employment dividend of 1.5 million jobs (Cavanagh 2009).

C. Displaced Pollution and Cost Savings from Improved Public Health

A third major cobenefit to clean and green energy—especially cookstoves, renewables, and efficiency—is improved public health and corresponding cost savings. The most salient example here relates to cooking. Burning firewood, dung, charcoal, and other fuels has severe health consequences. As the World Health Organization (WHO 2006, 8) explains:

> The inefficient burning of solid fuels on an open fire or traditional stove indoors creates a dangerous cocktail of not only hundreds of pollutants, primarily carbon monoxide

and small particles, but also nitrogen oxides, benzene, butadiene, formaldehyde, polyaromatic hydrocarbons and many other health-damaging chemicals.

There is both a damaging spatial and temporal dimension to such pollution. Spatially, it is concentrated in small rooms and kitchens rather than outdoors, meaning that many homes have exposure levels to harmful pollutants 60 times the rate acceptable outdoors in city centers in North America and Europe (WHO 2006, 8). Temporally, this pollution from stoves is released at precisely the same times when people are present cooking, eating, or sleeping, with women typically spending 3–7 hours a day in the kitchen (Masud, Sharan, and Lohani 2007).

Even when these homes have a chimney and a cleaner burning stove (and most do not), such combustion can result in acute respiratory infections, tuberculosis, chronic respiratory diseases, lung cancer, cardiovascular disease, asthma, low birth weights, diseases of the eye, and adverse pregnancy outcomes; as well as outdoor pollution in dense urban slums that can make air unbreathable and water undrinkable (Jin 2006). Table 4 shows the most common and well-established health impacts of indoor air pollution.

Table 4: Health Impacts of Cookstove Pollution

Health Outcome	Evidence	Population	Relative Risk
Acute infections of the lower respiratory tract	Strong	Children aged 0–4 years	2.3
Chronic obstructive pulmonary disease	Strong	Women aged more than 30 years	3.2
	Moderate	Men aged more than 30 years	1.8
Lung cancer	Strong	Women aged more than 30 years	1.9
	Moderate	Men aged more than 30 years	1.5
Asthma	Specified	Children aged 5–14 years	1.6
	Specified	Adults aged more than 15 years	1.2
Cataracts	Specified	Adults aged more than 15 years	1.3
Tuberculosis	Specified	Adults aged more than 15 years	1.5

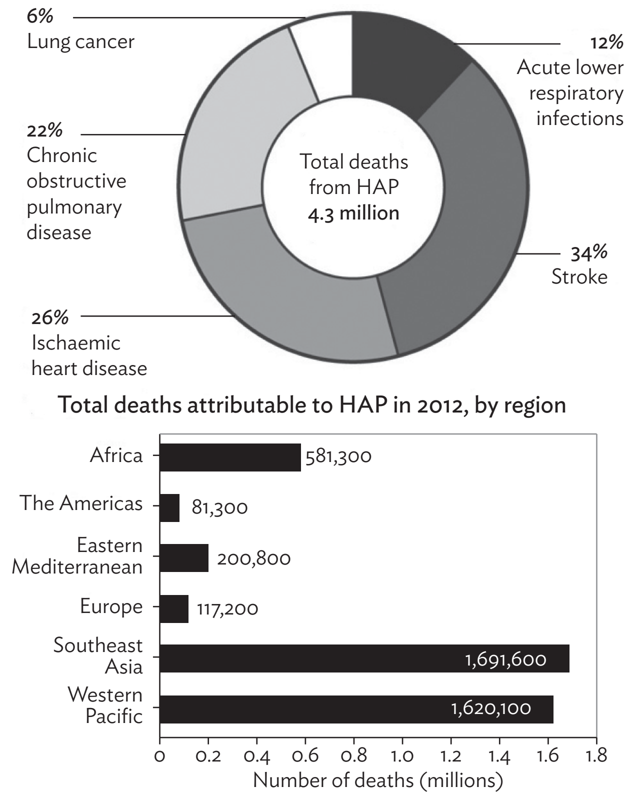
Note: "Strong" evidence means many studies of solid fuel use in developing countries supported with data from studies of active and passive smoking, urban air pollution, and biochemical and laboratory studies. "Moderate" evidence means at least three studies of solid fuel use supported by evidence from studies on active smoking and on animals. "Specified" means strong evidence for specific age or groups. "Relative risk" indicates how many times more likely the disease is to occur in people exposed to indoor air pollution than in unexposed people.
Source: World Health Organization. 2006. *Fuel for Life.* Geneva.

Strikingly, in 2012, indoor air pollution was ranked fourth on the global burden of disease risk factors at almost 5%, coming after only high blood pressure (almost 8%), tobacco smoking and second-hand smoke (about 7%), and alcohol use (about 6%) (Lim et al. 2012). This places it well ahead of physical inactivity and obesity, drug use, and unsafe sex. In March 2014, WHO (2014) projected that 4.3 million people die annually from household air pollution due to the use of biomass and coal as cooking fuels. Smith et al. (2014a) project that cookstove smoke is responsible for 4.8% of lost healthy life years, making it "the highest" among environmental risk factors. Figure 3, based on data from Subramanian (2014), breaks down these specific figures by type of disease and region.

This means that cleaner forms of cooking have immense health benefits and massive value in avoided health-care costs. Indeed, the cost of the burden to national health-care systems from cooking, not reflected in the price of fuelwood or energy, is $212 billion to $1.1 trillion (UNEP 2000; figures have been updated to 2010 dollars). WHO (2014) also estimates that if half of the global households that still use traditional fuels and stoves switched to cleaner cooking sources, over a 10-

year period, families would save $34 billion per year and generate an economic return of $105 billion per year.

Figure 3: Causes of Death from Household Indoor Air Pollution, 2012



HAP = hazardous air pollutants.
Source: Subramanian, Meera. 2014. Global Health: Deadly Dinners. *Nature* 509 (7502): 548–51.

Energy efficiency practices can also greatly displace and minimize pollution. As the National Academy of Sciences has noted (America's Energy Future Energy Efficiency Technologies Subcommittee et al. 2010, ix–x):

> Energy efficiency requires none of the environmental disruption seen in extracting coal, petroleum, natural gas, or uranium; depends on no wind turbines or hydroelectric dams or thermal power plants; emits no greenhouse gases or other pollutants; and can mitigate energy security risks associated with imported oil.

Its ability to reduce GHG emissions has propelled efficiency into a leadership position in the debate on global climate change.

Finally, there are health benefits to renewable electricity and low-carbon transport. The Intergovernmental Panel on Climate Change argues that the health cobenefits from low-carbon infrastructure include fewer deaths from heat waves and forest fires to better food security and improved curtailment of disease epidemics (Smith et al. 2014b). These can be roughly quantified into $40–$198 of positive health value per metric ton of carbon dioxide mitigated by 2020 (Balbus et al. 2014). One study from the International Institute for Applied Systems Analysis (IIASA) analyzed the cobenefits of pursuing a global mitigation strategy to keep temperatures at 2°C by enacting policy initiatives in the PRC, the European Union, India, and the United States (Rajaf et al. 2013). The IIASA team found that under a strong deployment of clean and green energy (an aggressive GHG emission mitigation strategy), expenditures on air pollution control would fall by €250 billion in 2050. Moreover, the study highlighted significant improvements in human health and average life expectancy as a result of these policy initiatives. In the PRC alone, a mitigation strategy was projected to reduce concentrations of particulate matter by 50% and improve average national life expectancy by 20 months. Decreases in ozone concentrations would also prevent nearly 20,000 cases of premature death. The study concluded by identifying a number of other indirect benefits arising from GHG emission reduction policies such as reduced acidification of forests, improved water quality, and enhanced watershed health. The International Monetary Fund similarly estimated in 2015 the cost of air pollution and associated health and economic damage that can be used to illustrate "avoided costs" when fossil fuels are replaced by clean energy. The amount monetized was staggering (Coady et al. 2015): $5.3 trillion, or 6.5% of global gross domestic product (GDP), with the largest subsidies in absolute terms in the PRC ($2.3 trillion), the United States ($699 billion), and the Russian Federation ($335 billion).

D. Enhanced Resilience to Disasters and Climate Change Vulnerabilities

A final significant cobenefit to clean energy is minimizing the eventual, severe impacts of climate change as well as improvements in resilience and adaptive capacity to natural disasters. The primary climatic benefits of clean energy stem from the fact that immediate efforts can stop the buildup of GHGs in our atmosphere. As climate scientist James Hansen et al. (2008) argue, mitigation is humanity's best path for "preserving a planet similar to that on which civilization depended and to which life on Earth is adapted" (Hansen et al. 2008). Immediate GHG emission reductions are needed to keep concentrations of these gases to within a 500–550 parts per million (ppm) range. As the IPCC (2014) implied in their latest global assessment, delaying invites disaster.

Another argument found in the literature is that clean energy and transport investments can enhance adaptation and resilience, making it easier for physical or natural systems to cope with climate change. Reducing the energy intensity of agriculture through better irrigation and less fertilization can also create farming techniques that are more resilient to drought (*The Economist* 2010). More efficient space cooling and heating can reduce electricity consumption while also making cooling more affordable for lower income groups (Sovacool and Brown 2009). Displacing the need for the exploration and drilling of offshore oil can prevent GHG emissions from fossil fuel combustion while diminishing the risk of oil spills and consequent stress on ecosystems (adaptation). Energy efficiency programs can reduce energy use and cut consumers' energy bills, translating into greater financial resilience to future shocks (Moser and Boykoff 2013).

Some investments, such as energy efficiency, can improve resilience in other ways. It has been estimated that, for instance, every dollar invested in energy efficiency mitigates uncertainty associated with reduced load, wear, and maintenance needs of the entire fossil fuel chain, even in hours when reliability problems were not anticipated by system managers. This is because efficiency gains depress the costs of locally used fuels such as oil, coal, and natural gas, and reduced demand in peak hours, the most expensive times to produce power. Efficiency gains also lessened costly pollutants and emissions from generators, improved the reliability of existing generators, and moderated transmission congestion problems. Furthermore, these initiatives, once put in place, were always at hand—available without delay or the needed intervention by system operators (Cowart 2001). The New York Independent Systems Operator, for example, sets a reserve criterion of 18% during times of peak demand to ensure overall system reliability. Accordingly, each megawatt-hour (MWh) of peak demand that customers avoid through energy efficiency means that utilities can subtract 1.18 MWh of total capacity needed. Quite literally, every single kilowatt-hour avoided through energy efficiency equates to 1.18 kWh of avoided supply (Komanoff 2002).

E. Trade-Offs and Complexities

This is not to say that cleaner stoves, renewable sources of electricity, efficiency and clean transport are without challenges or trade-offs. One study investigated five distinct strategic approaches designed to lessen a country's dependence on imported fuels, provide energy services at the cheapest price possible, enable universal access to electricity grids, mitigate GHG emissions, and foster energy systems that can operate under conditions of water stress and scarcity (Sovacool and Saunders 2014). The study concluded that each of the five strategies were, more often than not, in conflict with each other. A group that supports climate change mitigation might support a ramped-up presence for nuclear power, whereas a group supporting water security might seek to phase out nuclear power. No single strategy optimized all energy security criteria.

Thus, one pertinent aspect of progressive energy and transport policy appears to be that various components have the potential to trade off with each other. Encouraging demand-side management and energy efficiency can reduce peak congestion on electric power grids but would directly cut into the profitability of building natural gas peaking plants (Sovacool 2008). Energy taxes can promote efficiency and minimize waste, but also disfavor energy producers, especially Western and Gulf producers of oil and gas and global suppliers of coal (Kalicki and Goldwyn 2005).

Rapid changes in fuel efficiency and fuel economy requirements can lower dependence on oil but impose costs on automobile manufacturers that can reduce employment and hurt competitiveness. Creating a more efficient network of roads could lower congestion and improve automobile fuel economy in Indonesia, but would also only make it easier to extract and distribute coal, accelerating coal depletion and coal-related GHG emissions. Shifting from one reliable electricity source (such as hydroelectricity) to wind energy (intermittent and distributed) and coal (prone to volatile prices and GHG emission) would increase diversification, but could worsen overall system dependability. Diversification from historically cheap sources such as coal and hydro to more expensive ones such as wind and solar can improve availability but conflict with affordability and can also exacerbate dependence on foreign technologies that local planners may not own (Sovacool 2010).

This litany of trade-offs is emblematic of how improving some aspects of energy policy, or capturing cobenefits, can inherently conflict with other meaningful dimensions. We see such trade-offs in each of the four case studies explored in the next section.

IV. EXEMPLARY CASE STUDIES FROM ASIA

This section of the paper focuses on how to capture cobenefits in practice, concentrating its analysis on four case studies that span different sectors (cooking, electricity, efficiency, and transport), countries (Indonesia, the PRC, Japan, and Singapore), and time frames. Despite this heterogeneity of cases, each follows the same structure. It begins by briefly summarizing a historical description of the case examined before moving to discuss its cobenefits and finally challenges and trade-offs encountered.

A. Cookstoves in Indonesia, 2007–2012

Indonesia ran a large rural energy household program focusing on the conversion from kerosene stoves to liquefied petroleum gas (LPG) stoves (Budya and Arofat 2011). In 2007, planners initiated a massive energy program to convert primary household cooking fuels from kerosene to LPG in more than 40 million households in less than 5 years. When it ended in 2012, the program had been implemented in 23 provinces throughout Indonesia, with 43.9 million conversion packages provided to citizens as of 2012. Thirteen provinces were designated as "closed and dry," meaning that distribution of the first packages was completed and all subsidized kerosene was withdrawn. The program enabled the national gas company Pertamina to withdraw 8.2 million kiloliters of kerosene in 2012 and replace it with 3.2 million tons of LPG. This household "megaproject" provided an improved household cooking fuel, with its associated benefits in user costs, cleanliness, convenience, and environment, and reduced the government's huge subsidy for petroleum fuels.

The two most direct benefits have been reduced subsidies for kerosene and cost savings for households. In 2012, the Government of Indonesia reported that they were able to reduce the state's gross subsidy for kerosene by $6.9 billion due to the success of the LPG program (Bakar and Hashim 2011). Moreover, several surveys of LPG consumers have confirmed their overall satisfaction—and cost savings—under the program. A large majority of the recipients of conversion packages said that they can cook faster, have a cleaner kitchen, and, most importantly, reduce their expenditure for cooking fuel by approximately 30% (Pertamina Indonesia and WLPGA 2013).

Perhaps the most significant indirect benefit has been jobs and economic development through the creation of new industrial facilities. Most notable among these include the construction of 8 new LPG terminals, 53 LPG cylinder factories, 31 stove factories, 14 regulator producers, and 22 filling stations. In 2009, program evaluations estimated that the program generated $1.7 billion of investment across these types of facilities along with 28,000 new jobs (Budya and Arofat 2011). A second indirect benefit has been displaced emissions—with government audits suggesting that the program has reduced kerosene consumption by 6 million kiloliters pear year, equivalent to 8.4 million tons of carbon dioxide saved annually.

Achieving these cobenefits, of course, has not come without challenges. Some women have expressed a concern that the new stoves cook food too quickly; that is, they had grown accustomed to the fuel amounts and timing associated with an older stove and became quickly frustrated when the new stove "ruined" their meals (Sovacool and Drupady 2012). Moreover, the new stoves may not meet a family's entire cooking needs—families may wish to boil, bake, and broil with other cooking devices—and they still depend primarily on fuelwood in some locations, meaning they contribute to some of the burdens associated with its collection and use (Masera, Saatkamp, and Kammen 2000). In addition, the use of LGP, a fossil fuel, does conflict in a way with the stated goals of environmental sustainability and social well-being (Smith and Dutta 2011). Lastly, by focusing only on cooking, an admittedly laudable goal, the program did not enable other types of energy services such as electricity, productive and mechanical energy, or mobility needed to achieve modern lifestyles and levels of access (Sovacool et al. 2012).

B. Renewable Electricity in the People's Republic of China, 1988–2015

Our second case study deals with renewable electricity in the PRC. The PRC arguably began to promote renewable electricity seriously as early as 1988, when the central government first gave the National Development and Reform Commission responsibility for coordinating official positions in then-upcoming international climate talks. More recently, the Twelfth Five-Year Plan (FYP), adopted by the Government of the PRC in March 2011, has brought environmental and climate-oriented concerns to the forefront of national policy. Its targets included decreasing carbon intensity (carbon emissions per unit GDP) by 17% by 2015, increasing share of nonfossil energy in total energy mix from current 8.3% to 11.4% by 2015, and increasing research and development (R&D) expenditures on cleaner forms of energy supply from 1.8% GDP to 2.2% GDP (Xinghua News Service 2011).[4] New renewable energy production has also been driven by international trends such as the global market for carbon credits. As of 2010, roughly half of the certified emission reductions (CERs) in circulation under the Kyoto Protocol were produced by projects in the PRC, with roughly a third of the PRC's CERs being produced by wind projects (Fogarty 2011). In particular, on 27 February 2012, the PRC's National Development and Reform Commission announced a plan to develop a national quota regime intended to encourage renewable energy development (China Daily 2012). This system will define a required mix of renewable and conventional electricity sources to be applied on a region-by-region basis (Wang 2012).

Such targets do seem to be catalyzing the growth and acceptance of low-carbon technologies. In 2013, the PRC led the world in the largest amount of renewable energy capacity installed that year, and it ranked first in six different categories of renewable energy. It was home to approximately a fifth of the world's renewable power capacity, with an estimated 229,000 MW of hydropower capacity in addition to about 90,000 MW of other renewables (mostly wind) (REN21 2013; reporting data for 2012). Renewables, including hydro, met 27.5% of the country's electricity supply, a share almost twice that of the United States. In the PRC, for the first time ever, wind power generation increased more than generation from coal and surpassed and exceeded the output of nuclear power plants (REN21 2013). Behind the United States and Brazil, the PRC is also currently the third-largest producer of biofuels in the world. Table 5 presents slightly more updated data that show the PRC leading the world in annual investments in hydropower, solar photovoltaic, wind power, and solar water heating, in addition to leading the world for total renewable power installed including and excluding hydropower as well as total wind energy capacity (REN21 2015).

Taken collectively, these policies and trends are meaningfully altering the trajectory of the PRC's energy sector. Bloomberg New Energy Finance predicted in 2013 that the PRC will add an additional 1,583 gigawatts (GW) of new electricity capacity to its grid by 2030, and that renewable power will represent more than half of these new additions, meaning that renewable energy reaches "the same capacity level" as coal in 2030. That report forecast that "coal-fired power generation will decrease from 67% in 2012 to 44% in 2030, or 25 GW annually, while renewable generation will increase from 27% in 2012 to 44% in 2030, at 47 GW per year" (Bayar 2013).

4 See also Finamore (2011).

Table 5: Global Trends in Annual Renewable Electricity Investment and Capacity, 2014

(a) Annual Investment (2014)

	1	2	3
Investment in renewable power and fuels (not including hydro > 50 MW)	PRC	United States	Japan
Investment in renewable power and fuels per unit GDP	Burundi	Kenya	Honduras
Geothermal power capacity	Kenya	Turkey	Indonesia
Hydropower capacity	PRC	Brazil	Canada
Solar photovoltaic (PV) capacity	PRC	Japan	United States
Concentrating solar thermal power (CSP) capacity	United States	India	–
Wind power capacity	PRC	Germany	United States
Solar water heating capacity	PRC	Turkey	Brazil
Biodiesel production	United States	Brazil	Germany
Fuel ethanol production	United States	Brazil	PRC

(b) Total Installed Capacity

	1	2	3
Renewable power (incl. hydro)	PRC	United States	Brazil
Renewable power (not incl. hydro)	PRC	United States	Germany
Renewable power capacity per capita (among top 20, not including hydro)	Denmark	Germany	Sweden
Biopower generation	United States	Germany	PRC
Geothermal power capacity	United States	Philippines	Indonesia
Hydropower capacity	PRC	Brazil	United States
Hydropower generation[4]	PRC	Brazil	Canada
CSP	Spain	United States	India
Solar PV capacity	Germany	PRC	Japan
Solar PV capacity per capita	Germany	Italy	Belgium
Wind power capacity	PRC	United States	Germany
Wind power capacity per capita	Denmark	Sweden	Germany

GDP = gross domestic product, MW = megawatt, PRC = People's Republic of China.
Source: Modified from REN21. 2015. *Renewables Global Status Report*. Paris; reporting data for 2014.

This rapid increase in renewable electricity adoption has faced some difficulties, however. One of them is a continued reliance on fossil fuels as well. The PRC government has been building new, dirty power plants at a frantic pace to keep up with demand. In the electricity sector, more than three-quarters of all coal-fired power plants worldwide were built in the PRC in 2010, enabling coal to contribute to about 80% of the country's electricity generation. The PRC coal sector employs 7.8 million people and produces about 40% of the world's coal (WWF 2007). The resultant increase in GHG emissions from the coal plants added to the PRC grid in the last 5 years has already offset all of the gains made by the Kyoto Protocol and collective voluntary efforts around the world over the same period (The Energy Collective 2012).

As such, for the first half of 2013 the PRC government reported that ambient airborne particulate concentrations in 74 of the PRC's largest cities are three times the level considered safe under WHO guidelines (Bloomberg 2013). The World Bank similarly estimated that the economic burden of premature mortality associated with air pollution amounted to at least \$63 billion–\$272 billion in damages or as much as 3.3%–7.0% of national GDP (Deng 2006; McMichael 2007). Consequently, WHO (2007) estimates that 275,600 people die annually because of outdoor air pollution in the PRC. About 30% of river water is so polluted that it is considered unfit for agricultural, industrial, and electrical purposes (Carmody et al. 2010). Two-thirds of the PRC's 660 largest cities suffer from water shortages with 110 facing "severe" shortages, and water pollution throughout the country sickens at least 190 million people and causes 60,000 premature deaths every year (Economy 2007).

C. Energy Efficiency in Japan, 1999–2012

Japan's Top Runner Program shows how adept and nimble government interventions can be at promoting the widespread use of best practices in energy efficiency (across industrial manufacturing and household use) by closely monitoring technological advances (Komiyama and Marnay 2008; Siderius and Nakagami 2012).[5] Japan established the Top Runner Program in 1999 as a means of tying energy efficiency standards, by category, to 19 different products, ranging from automobiles and refrigerators to computers and DVD players, shown in Figure 4. Then, within a time period mandated by the government, the average of the weighted sales of each manufacturer and distributor must meet that new energy standard.

As Figure 4 also indicates, these savings reach as high as a 67.8% improvement for air conditioners, 78% for fluorescent lights, and 99.1% for computers over time. The program's goals are also strengthened by the Japanese concern for corporate image: "naming and shaming" companies for failing to meet standards is a highly effective tool used by the government. The program is expected to deliver \$3 billion in benefits in markets for lighting, vehicles, and appliances.

Perhaps the biggest single challenge facing the program, however, is the risk of a "rebound effect" where consumers increase consumption to accommodate more efficient (and often cheaper) energy use. Energy efficiency efforts such as Top Runner can decrease the marginal price for an energy service, increasing demand of that service as consumers reinvest the gains in additional consumption (Owen 2010). A variant of this thinking is known as the Jevons paradox, and it argues that efficiently using energy causes the overall cost of using energy to decrease. This, in essence, liberates resources for people to use, often in activities that consume more net energy (Alcott 2005).

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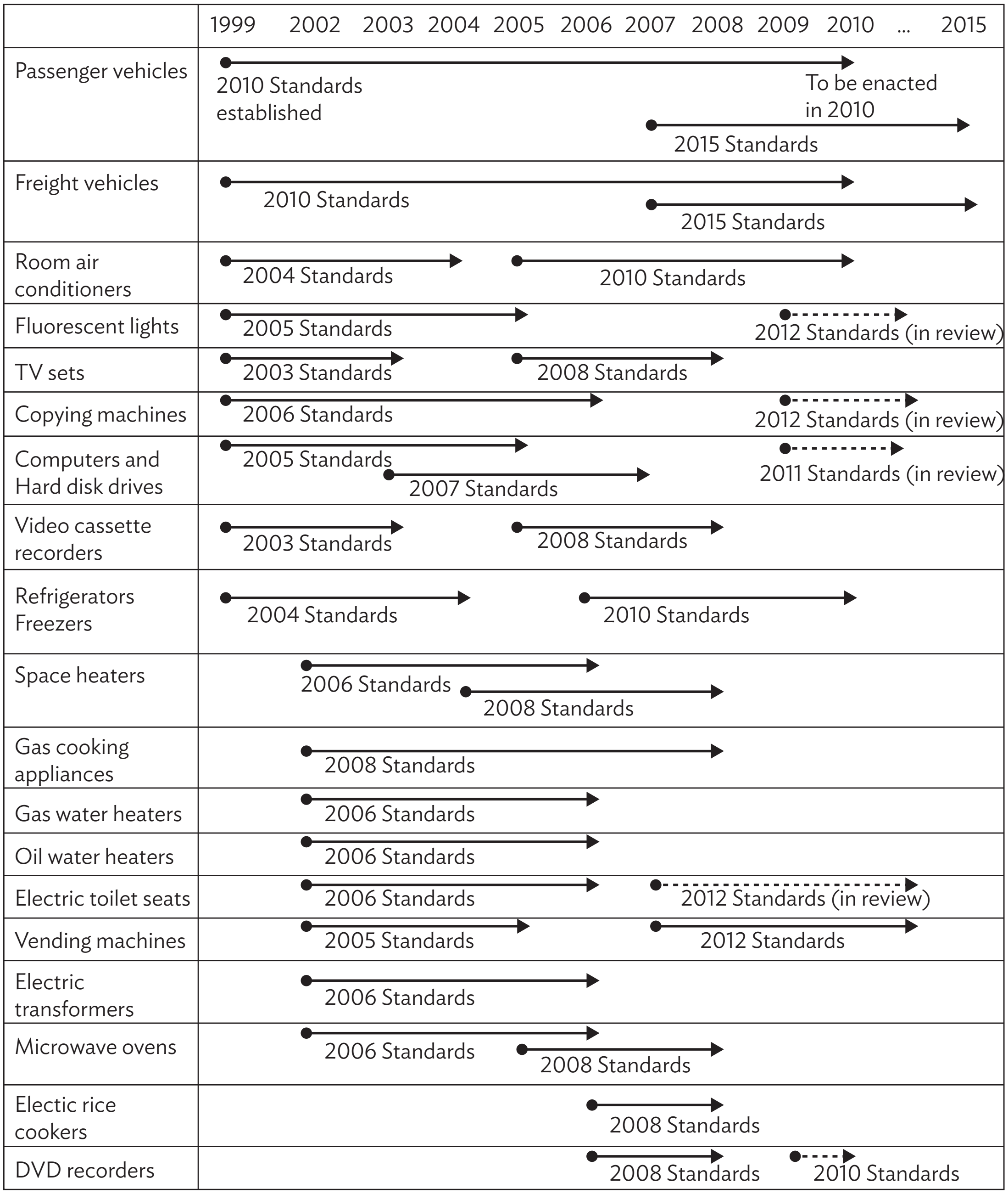
5 See also Kimura (2012).

Figure 4: 'Top Runner' Energy Efficiency Standards and Achievements in Japan

(a) Standards Applicable in 2012



continued on next page

Figure 4 continued

(b) Selected Efficiency Savings, Various Years

Product	Estimated Improvement with Top Runner Standards*	Results
Room air conditioners	66.1% increase in COP (FY 1997 vs 2004 freezing year)	67.8%
Refrigerators	30.5% decrease in kWh/year (FY 1998 vs FY 2004)	55.2%
TV receivers	16.4% decrease in kWh/year (FY 1997 vs FY 2003)	25.7%
Computers	83.0% decrease in kWh/year (FY 1997 vs FY 2005)	99.1%
Fluorescent lights	16.6% increase in lm/W (FY 1997 vs FY 2005)	78.0%
Vending machines	33.9% decrease in kWh/year (FY 2000 vs FY 2005)	37.3%
Gasoline passenger vehicles	22.8% increase in km/L (FY 1995 vs FY 2010)	22.8% (FY 1995 vs FY 2005)

COP = coefficient of performance, FY = fiscal year, km/L = kilometer per liter, kWh = kilowatt-hour, lm/W = lumens per watt.
Note: The starting and ending points of an arrow indicate the year of enactment for a particular standard.
Source: Modified from Kimura, Osamu. 2012. *Japanese Top Runner Approach for Energy Efficiency Standards*. Tokyo: Central Research Institute of the Electric Power Industry.

This rebound or "take-back" effect is stipulated as having direct and indirect consequences: the direct effect occurs when the extra income from efficiency implementation increases overall energy use. The indirect effect occurs when the extra income is used to consume other appliances more, leading to increased energy consumption (Greening, Greene, and Difiglio 2000). Though they did not find a meaningful rebound effect (above 15%) in their own study, nor has it been applied directly to the Top Runner program, Chitnis et al. (2013) did survey the recent literature on the topic and present their findings—across a broad array of areas including food, heating, electricity, and transport—in Table 6. The prospect of a large "backfire" associated with the introduction of improved technology could diminish the energy savings from a program such as Top Runner.

D. Mass Transit in Singapore, 1971–2009

Singapore relies on a mix of incentives and disincentives to promote more sustainable transport centered on minimizing the use of private cars and maximizing the use of mass public transit. So-called "sticks" raise the costs of driving a private automobile through purchase taxes and usage fees, whereas "carrots: encourage public transport and more efficient driving practices (Brown and Sovacool 2011). As a sign of its success, the Singaporean Ministry of Transport estimates that almost 5 million trips (about 60%) occur per day using mass rapid transit, light rail transit, and buses—impressive figures given that the country has a population of less than 5 million people.

Table 6: Estimates of Direct and Indirect Rebound Effects for Households

Number of Commodity Groups Studied	Abatement Action	Area	Measure	Effects Captured	Energy/Emissions	Estimated Rebound Effect (%)
150	Efficiency and sufficiency	Food; heating	Greenhouse gases	Income	Direct and indirect	45–123
300	Sufficiency	Food; travel; utilities	Carbon	Income	Direct and indirect	7–300
13	Efficiency	Transport; utilities	Carbon	Income and substitution	Direct and indirect	120–175
13	Efficiency	Transport; utilities	Energy	Income and substitution	Direct and indirect	12–38
6	Efficiency	Transport; heating; electricity	Energy	Income and substitution	Direct only	37–86
16	Sufficiency	Transport; heating; food	Greenhouse gases	Income	Direct and indirect	7–51
74	Efficiency	Transport; electricity	Greenhouse gases	Income	Direct and indirect	7–25
36	Efficiency and sufficiency	Transport; lighting	Greenhouse gases	Income	Direct and indirect	5–40

Source: Modified from Chitnis, Mona, Steve Sorrell, Angela Druckman, Steven K. Firth, and Tim Jackson. 2013. Turning Lights into Flights: Estimating Direct and Indirect Rebound Effects for UK Households. *Energy Policy Volume* 55: 234–50.

Driven by concerns that the traffic situation would quickly become unmanageable within the country due to its small size and growing population (and number of possible automobile drivers), government leaders embarked on the State and City Planning Project from 1967 to 1972. Deeply shaped by the geography of Singapore and its limited resources of land, the project resulted in a concept plan in 1971 that provided the framework for spatial and urban development oriented to creating a city center and road corridors (the plan has since been updated in 1991 and 2001) (Barter 2008). The project highlighted that patterns of driving and vehicle ownership were rapidly becoming unsustainable with the available land within Singapore and brought the matter of transport to the attention of senior government officials (Barter 2008). Officials responded by implementing a number of mechanisms to restrict the supply of, and curb demand for, private vehicles. The most influential of these mechanisms are presented in Table 7.

These innovative mechanisms would not have been nearly as successful if they had not been coupled to rigorous investments in public transit. Efforts began in 1973 with improvements of buses, including the forced mergers of bus companies, followed by the imposition of a professional unified bus company in 1973, the reorganization and streamlining of bus routes, the banning of pirate or independent taxis, and the creation of bus lanes in major corridors (Barter 2008; Santos et al. 2004). A $10 billion mass rapid transit (MRT) rail system opened in 1987 to support the already extensive 12,600 buses and 20,000 taxis in the city and light rapid transit. A fully automated rail system equivalent to the "People Movers" found in the United States was added in 1999.

Table 7: Major Measures Introduced to Curb Road Congestion in Singapore, 1972–2009

Year	Measure	Concise Description of Measures/Systems	Success Rate
1972	Additional Registration Fee (ARF)	Extra levy imposed on new vehicle, priced at 5%–140% of the vehicle's capacity and function.	Only initially. Scheme was revised in 1974 and 1975.
1975	Area Licensing Scheme (ALS)	Restrict access to central business district (CBD) from 7:30 a.m. to 2:00 p.m. on Saturdays through purchase of supplementary licenses.	Initial drop in traffic into the CBD was 45%. By 1988, drop was not sustained due to increase in employment in the CBD.
1987	Mass Rapid Transit (MRT)	Serves heavy passenger transit corridors.	Ridership rose from 346 million in 1998 to 360 million in 1999, an increase of 14 million.
1990	Vehicle Quota System (VQS)	Certificate of Entitlement (COE) is introduced, i.e., new car population allowed to grow at 3% in tandem with road capacity growth. Motorists now need to bid for the right to own a car.	With VQS, 41,000 fewer vehicles were registered between 1990 and 1993.
1994	Off-Peak Car (OPC) Scheme	Offer new and existing car owners the option to save on car registration and taxes in return for lower car usage.	Not very successful as most motorists preferred ready use of car for convenience.
1995	Road Pricing Scheme (RPS)	Manual road pricing scheme introduced for linear passage vehicle flow, i.e., remove bottlenecks at congested expressways or arterials outside CBD.	Initial drop in traffic volume along RPS monitored expressways dropped by 41% from 12,400 to 7,300 vehicles while public transportation travel speed increased by 16%.
1998	Electronic Road Pricing (ERP)	Automated road pricing to reduce the 147 enforcement personnel needed for RPS and replace ALS, OPC, and RPS.	Traffic volume on ERP monitored roads dropped by 17%.
1999	Light Rail Transit (LRT)	Serve as passenger feeder to existing MRT network.	Currently carrying payload of 39,000 passengers daily.
2009	VQS Revised	VQS modified to limit the growth of new cars to 1.5% per year	Expected to further reduce car ownership.

Source: Brown, Marilyn A., and Benjamin K. Sovacool. 2011. *Climate Change and Global Energy Security: Technology and Policy Options*. Cambridge, MA: MIT Press.

The collective benefits from Singapore's urban transport policies can be divided into four areas. First, Singapore has lower private vehicle ownership than other European and North American cities of similar size, economic activity, and income. While the fleet of vehicles in aggregate has more than doubled from the 1970s to today, its expansion has barely outpaced population growth, with about 100 cars per 1,000 people in 1970 and only 130 cars per 1,000 people in 2008, not counting foreigners and expatriates.

Second, Singapore's efforts have improved traffic flow and reduced congestion. The Area Licensing Scheme (ALS) system led to an almost immediate reduction in traffic by 50% and travel speeds increased from an average of 17.7 kilometers per hour (km/h) to 33.8 km/h during the first year it operated. The Electronic Road Pricing (ERP) system has also reduced traffic volume into the central business district by about 10%–15% during peak operation hours as compared to the ALS (Brown and Sovacool 2011), and it has shifted driving habits so that morning peak traffic is down 7.2%, midday traffic down 7.6%, and off-peak traffic up 28% (Brown and Sovacool 2011). More than 95% of expressways, roads in the central business district, and arterial roads were "congestion free" during peak periods from 2006 to 2008.[6] Congestion pricing and information schemes are estimated to have increased traffic throughput at intersections and expressways with a net cost savings of $30 million per year due to shorter delays and less time spent in traffic jams; less congestion also serves to lubricate commerce and increase productivity. This means that the entire Singaporean transport network is more efficient, with motorized passenger travel in Singapore consuming about 12,000 megajoules per capita (MJ/cap) compared to 30,000 MJ/cap for a typical Australian city (Barter 2008).

Third, taxes, fees, and programs such as the Vehicle Quota System (VQS) and ERP provide the government with hundreds of millions of dollars of revenue. Fixed vehicle taxes, purchase and ownership fees, and the Certificates of Entitlement (COEs) account for about a fifth of all government revenue, creating funds that are then invested back into transportation infrastructure along with housing, education, health care, and other socially desirable programs. While the implementation of the ERP system cost about $1.4 billion, annual revenue from the program was initially $350 million and operating costs only $7 million, meaning the system paid for itself in 5 years (Brown and Sovacool 2011). Currently, the ERP costs $20 million–$25 million to operate but produces annual revenues of $100 million.

Fourth, many components of the transport system are cheaper than other major metropolitan areas. The average price of an MRT ride in Singapore is $0.91 compared to $1.15 for New York and Tokyo; $1.40 for Hong Kong, China; and $2.45 for London; the average price of a bus ride is $0.67 for Singapore but $0.87 for New York; $0.96 for London; $1.11 for Hong Kong, China; and $1.38 for Tokyo. Mostly because of improved traffic flow, the average peak taxi fare for a 9-kilometer drive in Singapore is $9.39 compared to $12.35 in Hong Kong, China; $14.62 for New York; and $24.56 for London (Land Transport Authority 2008).

Nonetheless, Singapore continues to face a host of transport-related challenges. First comes increasing demand for travel and aspirations for the ownership of private automobiles. The Singaporean Land Transport Authority expects private travel demand to increase from 8.9 million journeys a day in 2008 to about 14.3 million journeys a day by 2020 (Land Transport Authority 2008). Over the period between 1997 and 2004, however, the share of public transport during morning peak hours dropped from 67% to 63%. Less than 15% of people commuted to work by car in 1980, but about a quarter did in 2000 (Brown and Sovacool 2011), and the total vehicle population grew from 670,000 in 1996 to 850,000 in 2007 (Land Transport Authority 2008). The number of vehicular trips has grown by more than a factor of three, from 2.7 million trips in 1981 to 7.8 million trips in 2005 (Brown and Sovacool 2011). At the same time, Singapore is running out of space for cars, with 12% of its land area already occupied by roads and little physical space for growth. Even the VQS, which now restricts car ownership to a growth rate of 1.5% per year, still permits ownership to grow substantially over time.

With rising levels of affluence and changing demographics, the expectations for many Singaporeans have been realigned to value the increased mobility and luxury offered by private automobiles. In absolute terms, the number of vehicles (and associated GHG emissions with operating them) continues to increase. The falling cost of cars due to increased competition from overseas suppliers and the availability of cheaper models only adds to this challenge, with a new Toyota Corolla costing about $66,000 (inclusive of all taxes and fees) in the 1990s but only $40,000 today, and even less expensive automobiles from the PRC and the Republic of Korea running for less than $30,000, all

[6] "Percentage congestion free" is defined as the percentage of expressways with average speed above 45 km/h or percentage of CBD and/or arterial roads with average speed above 20 km/h.

inclusive. These falling costs may motivate people to purchase the maximum number of cars permitted under the VQS.

Furthermore, many of Singapore's policies have been technology and/or capital intensive. The ERP, for example, employs a combination of complex radio frequencies, imaging, and smart card technologies, optical detection, cameras, and computers working simultaneously. The system necessitated 10 years of planning, testing, and preparation including a pilot program that involved fitting 250 vehicles with vehicle transponders and 4.8 million transactions (Brown and Sovacool 2011). Before the ERP began operation, the government managed a free program to outfit 97% of all vehicles in Singapore with transponders. Foreign cars visiting Singapore must pay to rent a battery-powered device so they can travel on ERP roads. Each of these policies required substantial amounts of time, human resources, and money to implement.

Lastly, the urban transport policies in Singapore, while they have helped curb traffic and congestion, have still heavily favored motorized forms of transport. That is, they have given a high priority to maintaining traffic flow for automobiles, buses, and taxis, and incentivizing commuters to use the MRT. This trend may be counterintuitive to attempts to improve the safety of nonmotorized forms of transport (such as walking, jogging, running, skating, or bicycling), and eliminating the congestion of private automobiles also removes the speed advantages for mass transit (Brown and Sovacool 2011). Plans for the future also reflect this bias, with much discussion of community car-owning schemes, an expansion of the off-peak program, and a transition to electric vehicles, but less effort to encourage walking and biking.

V. CONCLUSIONS AND POLICY INSIGHTS

At least four distinct conclusions and policy implications can be derived from the data in this paper. First, low-carbon forms of energy supply and infrastructure have immense positive and admittedly difficult-to-monetize cobenefits. Cleaner forms of cooking have immense health benefits and massive value in reduced morbidity and mortality and corresponding avoided health-care costs that could reach into the trillions of dollars each year. Renewable sources of electricity not only provide electrons and kilowatt-hours, they do so in ways that generate more jobs per unit of energy delivered and enhance diversification and energy security. Investments in energy efficiency have been shown to enhance innovation and economic competitiveness, generate economic returns, improve resilience, and displace GHG emissions and other forms of pollution at the same time. Low-carbon urban transport infrastructure has been demonstrated to reduce traffic congestion, minimize GHG emissions and pollution, and create an affordable, popular platform for transit simultaneously. These benefits, moreover, are proportional to the amount invested in a particular policy or the volumes and scale economies achieved by particular forms of technological diffusion. Simply put, the more invested, the exponentially greater degree of cobenefits gained.

Second, achieving these benefits required strong government commitment in each case, as well as a progression of policy instruments implemented consistently over time. Indonesia's LGP project was steered at the executive level by the country's Vice-President and worked only by stimulating cookstove adoption while also disincentivizing the use of kerosene through the repeal of subsidies. The PRC's promotion of renewable electricity has depended on strong state support in the form of binding national targets, adherence to the Kyoto Protocol and the global carbon credit market, and (most recently) discussions of emissions trading. Energy efficiency in Japan depended on state-led targets enforced through strict financial penalties as well as publicly "shaming" poor industrial performers. Singapore has pursued a synergetic approach to urban transport policy that involves both "supply-side" and "demand-side" elements as well as "carrots" and "sticks" (Brown and Sovacool 2011). Aspects have included restraint of vehicle ownership and vehicle moratoriums, steady improvement of public mass transit, road pricing schemes, and the provision of real-time information to drivers. "Supply-side" components have invested in train and bus infrastructure and constructed electronic road pricing schemes, whereas "demand-side" components attempt to alter behavior in favor of public mass transit by restricting the number of private vehicles through quota systems and higher vehicle fees. Stable, consistent, and strong government support is a common theme in all of these cases; governments did not let markets or other actors lead. Put another way, markets will not capture cobenefits on their own; the examples from Indonesia, the PRC, Japan, and Singapore are not necessarily "cost-effective" in markets where fossil fuels are free and/or no price for externalities such as carbon exists. Correcting market and policy failures is not always costly in economic terms (use of resources and other inputs), but reform initiatives must confront a serious array of challenges including political difficulties, distributional consequences, social barriers, and analytical difficulties.

Third, and drawing from this point about difficulty, more research is needed and considerable gaps exist. More specific recommendations on how to deal with the trade-offs in each country—and others not listed—would be useful, as would creating a typology of possible policy pathways for identifying and maximizing cobenefits. Efforts, for instance, could center on a mix of technology progress (e.g., sharp decline in solar and wind power costs), removing subsidies on fossil fuels, developing local manufacturing capacity for clean solutions, and good business models. Shorter-term or easier to achieve research objectives could include:

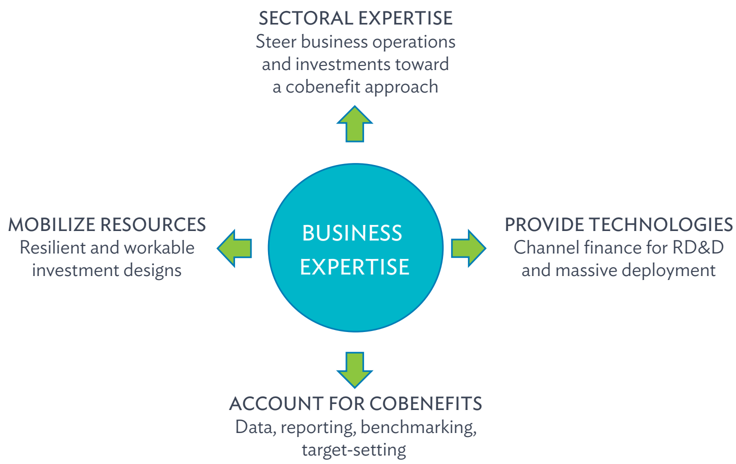
- ranking projects by cobenefit returns,
- creating more credible fiscal frameworks,
- highlighting the benefits of opportunistic investment in green and clean projects (the winners and the positive distributional aspects), and
- managing fiscal policy in a timely fashion.

Longer-term or more difficult to achieve objectives could include:

- concentrating on correcting market and policy failures that could impede the growth of rapidly expanding green and energy sectors;
- considering past path dependence, need for scale, and the role of domestic endowments;
- pricing energy and reforming subsidies; and
- manufacturing credible policies that are "long, loud, and legal."

In addition, a well-designed business engagement process could improve upscaling efforts. Figure 5 offers a sketch of how such a platform may look. The Asian Development Bank, in particular, can provide analytical, policy, and financing support to developing member countries in these various areas.

Figure 5: Clean Energy Cobenefits Business Engagement Framework



RD&D = research, development, and deployment.
Source: Author.

Fourth, and last, despite these complexities, the case studies here do offer a possible template that other countries could model when designing their own green growth strategies. To be sure, each country is unique and each program had to confront challenges. Indonesia saw user resistance to cleaner and faster cooking devices by some households; the PRC's scramble for energy has forced it to push for both renewable and fossil-fueled electricity at the same time; Japan's energy efficiency savings may be offset by partial rebound effects; and Singapore continues to see the rise of private cars despite strong disincentives. Nevertheless, these cases also serve as empirical success—living laboratories, so to speak—where aggressive clean energy and climate policies have overcome the usual obstacles to successfully meet targets and reach impressive milestones. They deserve credit for serving as innovation policy laboratories that many other communities could learn from.

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Cobenefits and Trade-Offs of Green and Clean Energy

Evidence from the Academic Literature and Asian Case Studies

This paper assesses the positive cobenefits of promoting green and clean energy in Asia. It first defines what is meant by "clean" energy across the four technological systems of cooking, renewable electricity, energy efficiency, and urban transport. It summarizes at least four general types of cobenefits to investing in these systems: (i) diversification and enhanced energy security, (ii) jobs and green growth, (iii) displaced pollution and associated cost savings, and (iv) enhanced resilience and adaptive capacity to things like climate change and natural disasters. The next part focuses on four case studies of where cobenefits have been delivered in practice: liquefied petroleum gas stoves in Indonesia, renewable electricity generation in the People's Republic of China, energy efficiency in Japan, and mass transit in Singapore.

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