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Policies for Energy System Transformations: Objectives and Instruments

Convening Lead Author (CLA)

Mark Jaccard (Simon Fraser University, Canada)

Lead Authors (LA)

Lawrence Agbemabiese (United Nations Environment Programme)
Christian Azar (Chalmers University of Technology, Sweden)
Adilson de Oliveira (Federal University of Rio de Janeiro, Brazil)
Carolyn Fischer (Resources for the Future, USA)
Brian Fisher (BAEconomics, Australia)
Alison Hughes (University of Cape Town, South Africa)
Michael Ohadi (University of Maryland, USA)
Kenji Yamaji (University of Tokyo, Japan)
Xiliang Zhang (Tsinghua University, China)

Contributing Authors (CA)

Igor Bashmakov (Center for Energy Efficiency, Russia)
Sabine Schnittger (BAEconomics, Australia)
Julie Tran (British Columbia Utilities Commission, Canada)
David Victor (University of California, San Diego, USA)
Charlie Wilson (Tyndall Centre for Climate Change Research, UK)

Review Editors

Mohan Munasinghe (Munasinghe Institute for Development, Sri Lanka and University of Manchester, UK)
Ian Johnson (Club of Rome, Switzerland)

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Executive Summary

The Global Energy Assessment (GEA) emphasizes the importance of energy to all societies, which explains a longstanding tendency for governments to be closely involved in the energy sector. The nature and extent of this involvement – the degree and types of energy-related policies – depends on a government's ideological orientation, the particular energy resource endowment in its jurisdiction, the development level of its economy, and specific concerns of its society with respect to energy access, energy security, and the environmental and human health impacts of energy supply and use.

In every country, energy's critical role for the goal of sustainable development is widely acknowledged. This means that energy-related policies need to be assessed in terms of performance with respect to the social, economic, and environmental dimensions that are encompassed by the concept of sustainable development. Ideally, energy-related policies will make advances with respect to all three of these critical sustainability dimensions. But frequently policymakers are faced with difficult trade-offs in which improvement in one dimension is at the cost of another. Thus, the first goal of energy-related policy design should be to seek win-win opportunities for simultaneously advancing social, economic, and environmental goals. When this is not possible, the goal should be to apply decision-support mechanisms that integrate diverse social objectives and values into the policy design process, such as the application of multi-criteria analysis as described by Munasinghe (1992; 2009).

Cluster I of GEA presents social, economic, and environmental dimensions of sustainable development as related to energy. These include social goals (Chapter 2), environmental protection (Chapter 3), human health (Chapter 4), energy security (Chapter 5), and economic development (Chapter 6). GEA establishes specific normative goals in these areas, chosen to reflect broad societal aspirations with respect to (1) alleviation of poverty, including universal access to modern forms of energy; (2) improved human health, including quality of life indicators; and (3) environmental sustainability, including indicators of biodiversity, water quality, and air quality.

Cluster II assesses the potential contribution of energy to these normative goals with detailed analyses of the existing and potential energy system. This includes energy efficiency-reducing energy use, while sustaining and even increasing energy services. It also includes specific energy supply options associated with socially acceptable applications of renewable energy, safe uses of nuclear power, and cleaner uses of fossil fuels. Many of the chapters within this cluster describe detailed policies with respect to, for example, energy efficient buildings or the safe use of nuclear power or protection of human health.

Cluster III provides an integrating analysis of these energy options. Of particular note is the exploration in Chapter 17 of a set of scenarios or pathways showing the potential evolution of the energy system on a sustainable development trajectory. With reduced energy use – i.e., greater energy efficiency, conserver lifestyles, urban form changes, reductions in material and water use that cause reduced energy use – potentially making a great contribution, Chapter 17 includes one pathway in which the efficiency option is pushed particularly aggressively. This scenario is enhanced by the multiple co-benefits associated with less energy supply and use. A much-expanded role for renewable energy is likewise associated with multiple benefits in many jurisdictions, such as improved security of supply from diverse domestic sources and reduced greenhouse gas (GHG) emissions. Thus, a special emphasis on renewable energy plays a key role in some energy system pathways.

Finally, Cluster IV of GEA is focused on policy, the means by which humanity might realize these pathways of energy for sustainable development – pathways that require a rapid and dramatic transition of the energy system when seen from a global perspective. Cluster IV is comprised of four chapters; this introductory chapter (Chapter 22) surveys the spectrum of energy-related policy objectives and policy measures, including examples of government involvement in the energy sector to reach both general and specific objectives of energy for sustainable development.

Text boxes in this chapter provide examples of real world policy efforts to achieve energy-related objectives. The chapter includes key policies that must be applied to meet the goals of sustainable development. It also presents specific policies necessary to achieve the sustainable development energy pathways of Chapter 17. Some of these policies are generic, and could be applied in widely different contexts, while others are more focused.

This sets the stage for subsequent chapters that focus on three specific policy challenges, namely: (1) extending energy access in the developing world (Chapter 23); (2) stimulating energy system innovation (Chapter 24); and (3) building human and institutional capacity for energy transition, especially in developing countries (Chapter 25). Finally, it should be noted that most chapters of GEA include some discussion of policies, in some cases quite detailed.

22.1 Introduction

For the purposes of policy analysis and design, the energy sector has specific policy challenges. These represent a further refinement and specification of social, economic, and environmental sustainability dimensions. These challenges reflect issues emerging throughout GEA. Some of them are only addressed via policy analysis and mechanisms presented here in Chapter 22. Market power in the energy sector, especially due to natural monopoly conditions in network industries like electricity, is one particular concern. Another is the challenge of effectively managing wealth associated with valuable resource endowments, especially from oil and natural gas. Yet another concern is the challenge of the energy system's contribution to GHG emissions and the risk of climate change. While energy-related emissions of GHGs are just one of many environmental impacts and risks associated with the energy system, the threat of climate change requires a global effort. Thus, preventing climate destabilization is a public welfare problem on a global scale and the transition of the energy system is a critical component in addressing this challenge.

Eight specific energy-related policy concerns, identified below, are addressed in this chapter.

1. Because energy is such a critical input to the modern economy and development of society, *energy access* – at an affordable level to meet basic human needs and to offer opportunities for social and economic development – is a key objective. This is especially the case for developing economies and for energy services that benefit those at the lowest income levels. Because these segments of society are least able to afford energy systems on their own, often governments intervene to provide them publicly or through subsidies for an adequate level of service. Chapter 23 addresses this topic in detail.

2. One mistake of past policy efforts aimed at improving energy access was to assume that technology adoption and capital formation were mainly linear processes of innovation and investment that depended little on the surrounding social, cultural, technical, financial, and institutional environment. Research into past failures, however, has indicated that an "enabling environment" is critical, and this has led to an increasing policy emphasis on *developing energy-related social capacities*. This refers to improving human, technical, financial, social, organizational, and institutional capacities, which will be critical in fostering a major transition of the energy system from its current character to one in which energy access is widespread and human and environmental impacts are dramatically reduced from today's situation. Chapter 25 addresses this topic in detail.

3. One indicator of successful industrial economies is that they have organized their energy systems to ensure access to affordable energy for almost all members of society. But energy access does not necessarily ensure *energy security*, the assurance that this access will not be overly vulnerable to major technological problems, geopolitical conflict, terrorist sabotage, or other significant types of disruptions. In this chapter the key components of energy security – as described in Chapter 5 – are summarized, and policies to foster social and economic aspects of sustainable development are presented.

4. The production and delivery of energy is capital intensive, requiring large investments in finding, extracting, developing, processing, transporting, and retailing. Capital-intensive activities are frequently associated with economies-of-scale, meaning that a large facility or company can provide energy at lower cost than several smaller companies. In certain sectors, like electricity, these economies-of-scale foster "natural monopolies" (utilities), where vesting a single firm with monopoly service provision is the lowest cost option for society. However, firms that operate as monopolies lack the incentive to provide goods at marginal cost as compared to competitive industries. Therefore, governments may employ policies or different types of controls – e.g., a regulated corporation – to *manage energy-related market power*. In some other energy sectors, like the petroleum industry, strong economies-of-scale mean that a few companies may be able to dominate various aspects of the market. Some degree of policy intervention may again be desirable, although unlike a natural monopoly this may involve efforts to reduce market power rather than to countenance the establishment of a regulated or state-owned monopoly.

5. Governments face special challenges when *managing valuable energy resource endowments* and especially the substantial revenues they can generate. For countries that have few exports other than energy, government tends to play a special role in managing these exports and allocating the large earnings. The experiences with government management of these resources have varied widely. For some countries, highly valued energy resources, like oil and natural gas, have been a boon for national treasuries and a stimulus for economic growth. But such endowments can cause substantial challenges, as evidenced by mismanagement of resource revenues, negative effects on other sectors of the economy, and even rent-seeking corruption within government and industry. In the extreme, a "resource curse" can occur – the paradoxical outcome in which a country with a rich resource endowment remains poor, in part because of mismanagement of that endowment.

6. With the expansion of the world's economy, the need has grown dramatically to *reduce environmental and human health impacts* of the energy system. Energy use affects humans and the planet's ecosystems at all scales, from uncontrolled indoor air emissions when combusting solid fuels for domestic cooking and heating in unventilated areas, to rising sea levels, extreme weather events, and new epidemiological threats from climate change. Public

policy has a critical role to play in ensuring that the impacts and risks from energy supply and end-use are reduced, in some cases dramatically. Chapter 3 disscusses the relationship between energy and the environment while Chapter 4 addresses energy and health in further detail.

7. If humanity is to achieve significant progress in pursuit of objectives like improved energy access and security, or reduced environmental impacts, it will need to *accelerate the rate of innovation, development, and dissemination of desirable energy-related technologies*. Governments can pursue policies that aim to overcome barriers to such technological transitions, ranging from public support for research and development (R&D), to programs that assist the initial market penetration of targeted technologies, to educational and institutional developments that foster an enabling environment for adopting and sustaining new technologies. Chapter 24 addresses this topic in detail.

8. The increasing globalization of the world's economic system is equally reflected in its energy system. Oil has long been traded on a global basis and this is now the case for coal and natural gas. Some regions also trade electricity. At the same time, the environmental impacts of energy use are also becoming global, especially the risk of climate change, caused in large part by the production and combustion of fossil fuels. These international dimensions of many energy-related challenges require a much greater effort to improve *coordination and implementation of international energy-related policies*, a necessity that has been recognized during the past few decades by major energy sector participants.

These eight energy-related policy goals present governments with a complex array of issues. But the policy challenge is complicated further by the need for consistency between energy-related policies, on the one hand, and the host of other government policies focused on goals like poverty alleviation, economic development, education, health, national security, and macro-economic stability, on the other. Policy consistency is a great challenge and it always should be a major focus of the design and evaluation of policy options.

In addressing these energy-related policy goals, governments have various instruments available to them. While the potential options are numerous, in a generic sense, policy is usually manifested as:

- direct public ownership or control;
- regulations and standards;
- information, education, and public engagement to promote voluntary actions;
- financial charges, such as taxes and fees; and
- subsidies, such as grants, low-interest loans, and rebates.

In choosing among these policy options, governments can rely on key evaluative criteria that policy analysts conventionally apply when assessing policies (Hahn and Stavins, 1992). These criteria are used to assess the ability of different policy options to meet their goals in a number of different ways:

- *effectiveness* – the ability of a policy to achieve the intended objectives;
- *economic efficiency* – the ability of a policy to achieve objectives at the lowest possible cost to society;
- *administrative feasibility* – the ability of a policy to avoid imposing a functional burden on government that thwarts successful implementation, such as through bureaucratic ineffectiveness or excessive information and monitoring requirements;
- *equity* – the effect of a policy on income distribution and on disadvantaged groups within society;
- *political acceptability* – the extent to which a policy can garner sufficient political support to be enacted and effectively sustained;
- *policy robustness* – the ability of a policy to perform well under highly uncertain and widely contrasted futures; and
- *policy consistency* – the extent to which a policy works in concert and not in conflict with other policies.

Policy effectiveness is often more challenging than it appears to non-experts. One key reason is that governments and public decision-making processes are sometimes portrayed in a simple way that fails to recognize factors that can cause policy impairment and policy failure. In fact, the list of factors is quite large. Small groups who are negatively affected by a policy, which otherwise has a net social benefit, can block the policy if they have strong leadership or include powerful interests. This kind of challenge may impede the development of some forms of renewable energy, for example. Powerful groups in society may gain excessive influence over the bureaucracy or politicians and may act more in their special interests rather than in the broader social interest.

Once implemented, a policy may shift the incentives in society such that people act in ways that counteract a policy's intent; this is sometimes called "moral hazard" in policy design. Corruption of politicians or bureaucrats is always a risk, though hopefully less so in more open societies. Policies that seem good on the surface could have very high transaction costs that thus impede their successful implementation. Finally, if the benefits of a public good are accessible to all, there is a risk of free-riders, agents who do not contribute to the costs yet share in the benefits, which erodes the social will to provide the public good. All of these factors must be considered when designing and comparing the effectiveness of policy options.

In the same vein, other policy evaluation criteria each present their own specific challenges. Economic efficiency is difficult to achieve when those who may be negatively affected by a policy pressure government to reduce the costs they would face under an efficient outcome. Careful policy design, however, can balance the equity objective and the efficiency objective by various redistributive mechanisms that reduce inequitable outcomes without blunting the economic efficiency requirement for clear pricing signals to suppliers and consumers.

When comparing or combining policy options, designers of energy-related policy need to assess performance against these criteria. Because no single policy is likely to outperform all others in all of these criteria, some form of multi-criteria decision analysis is an essential component of the policy development process. The outcome of this analysis will depend on the relative weights that decision makers, and society as a whole, place on each of the criteria. In some circumstances equity concerns may have an especially strong weighting, while in others it may be environmental effectiveness or economic efficiency. For a given energy policy objective, decision analysis is useful to analyze the multiplicity of policy options and of policy evaluative criteria and help the decision maker assess the trade-offs associated with one or a package of policies.

The following list provides a general description of some key trade-offs that policymakers must navigate when designing and evaluating policies for sustainable energy objectives.

- Policymakers must find an appropriate balance, in a given circumstance and setting, between the role of public authorities, on the one hand, and the delegation of responsibility for decisions about land-use, technology, and behavior to firms and households acting in a market context, on the other. Thus, in some cases, governments may wish to promote and support – with R&D, subsidies, and focused regulation – a specific technology or fuel in order to ensure its rapid dissemination. In other cases, governments may try to leave it to the market to determine which technology or fuel will actually emerge, especially when government is faced with great uncertainty about future technological evolution, costs, and preferences.

- Policymakers must find an appropriate balance between policies that are going to drive rapid change and policies that have a good chance of political acceptance. Ideally, a policy does well on both counts, but often some degree of trade-off is required.

- While policies should be as simple as possible from an administrative and bureaucratic perspective, it is important that they include sufficient sophistication in terms of experimental design, monitoring, and hindsight evaluation so that their effectiveness can be assessed and their design improved over time.

- Policy assessments are necessary to help navigate choices about policy design when there are vested interests making strong claims about evidence that may or may not be supported by rigorous research. Examples of such complex choices include a tax on greenhouse gas emissions versus cap-and-trade systems, or fixed feed-in tariffs that guarantee a price for renewable electricity versus renewable portfolio standards that guarantee a market share.

- Policymakers must find an appropriate balance between the benefits to current versus future generations from valuable energy resource endowments. The outcome of this trade-off analysis could vary considerably, depending on: (1) the current level of well-being in the country or region; (2) the expected longevity of the resource endowment; (3) the likely future value relative to the present; and (4) the capacity of a government to ensure benefits to future generations through saving and reinvesting current returns from resource exploitation.

- Consideration must also be given to the stringency of the targets set by a policy, such as the level of greenhouse gas emission abatement. Policymakers have to decide whether the future costs and risks of not taking action – e.g., on climate change – outweigh the costs and risks to society of immediate action. These decisions will involve an assessment of the trade-off between the current and future welfare of society based, in part, on the risk of a negative outcome in the future.

Within the context of all these factors, another influence on policy choice is the ideological expectation of the role of government in the energy system. Decisions in this regard often hinge on a larger political debate around control over the economy. Should governments play a strong role, or are they willing to keep a distance and vest outcomes in individual decisions made by the myriad of actors in energy markets? The answer to this depends on institutions, goals, values, and resource endowments that can vary dramatically by country and region. Policies that work for highly industrialized countries, with a long tradition of market economies and relatively effective public institutions, may be inappropriate – or at least merit substantial modification – in developing economies. Countries that place great concern on the assured delivery of particular quantities of energy may be less willing to trust markets than are countries where competitively priced energy and market allocation has been the norm for decades. Countries where much of the population has no access to modern energy commodities may be less willing to assume that deregulated markets can meet the needs of their citizens if they have failed to do so thus far.

These kinds of decisions about the role of government and public policy in the energy sector vary by country, but also by energy service and commodity. Some countries, for example, have been wary about allowing market forces to govern commodities that the government considers strategic, even as they embrace markets in other parts of the economy. For most of the past few decades, the French government has played a dominant role in its electricity sector and in development of nuclear power, while playing a less dominant role in petroleum and natural gas. Energy policy in practice, therefore, requires that each country and region find the policy mix that best meets its goals and particular circumstances.

The following sections of this chapter include a detailed discussion of each of the eight energy-related policy goals described above. Each discussion includes descriptions and examples of policies available to further the goal, including case studies of real-world policies in different jurisdictions that present both successes and frustrations. Because three of these energy-related policy goals have separate chapters dedicated specifically to them – energy access, technology innovation, and capacity development (Chapters 23, 24, and 25, respectively) – the treatment here is cursory. Finally, it should be noted that most chapters of GEA include some discussion of policies, in some cases quite detailed.

22.2 Part I: Eight Energy-related Policy Goals

22.2.1 Increase Energy Access

Access to energy is one of the most urgent objectives for sustainable energy policy over the coming decades, which is why GEA dedicates Chapter 23 to this issue. Our treatment here is therefore limited to a brief description of the key issues for policy design.

About one quarter of humanity lives without access to electricity and more than a third has no access to liquid and gaseous fuels. The Millennium Development Goals for social and economic advancement will not be achieved without expanded access to clean and affordable energy. Access to energy is intimately linked with industrial productivity, communications, mobility, comfort, and other benefits that are key contributors to economic and social development. Access to electricity, in particular, contributes to higher levels of education, increased access to information, improved health care, and more effective institutions and communication networks. All of these improvements play a role in the alleviation of poverty and development of civil society (World Bank, 2000; UNDP and World Bank, 2005).

While markets can play an important role, universal access to energy is seen as a public responsibility because the benefits of its provision surpass those directly captured by individuals in their everyday participation in markets, extending to the wellbeing of all of society. During the twentieth century, governments in today's developed countries recognized the importance of access to electricity and used a combination of state enterprises and public subsidies to develop electricity production and distribution systems. Rural electrification subsidy programs were particularly important in the widespread electrification that occurred over just a few decades, largely through the activities of public corporations or publicly supported cooperatives.

While the key focus of these subsidies was often expansion of the grid into poorer regions and non-urban areas, there were also policies to ensure that a minimum amount of electricity would be affordable to low-income households. For this, utilities developed electricity tariffs such as lifeline rates: a low initial price for base levels of electricity consumption, with higher prices for any additional consumption.

Similar policies have been pursued by developing countries for providing access to electricity. These governments and utilities usually fund expansion of the electric grid into underserved areas and provide special rates for low-income households and farmers.

Unfortunately, in many countries, expansion of electricity access has not kept pace with population growth, diminishing the likelihood of achieving the Millennium Development Goals for energy access. There are multiple reasons for this failure. First, the magnitude of the objective is truly daunting, requiring a rate of investment and electric capacity expansion that far exceeds what was even achieved in the most successful of industrialized countries over the past century. Second, in some cases, publicly operated utilities and state enterprises have performed poorly, notably in terms of making bad investments, exercising poor management practices, providing unjustifiable cross-subsidies between customer classes, and countenancing corruption. Third, in some cases, private investment, whether local or foreign, has been misdirected or even detrimental to local socio-economic development.

Energy access policies may perform best when they find a balance between mobilizing market forces to provide funds for expansion of electricity generation and distribution systems, and involvement of governments and non-government organizations to ensure social development and access for society's poorest and most isolated members – access that would not occur if the sector were simply left to private markets. Moreover, it is essential to link energy access with policies that improve access to other government social programs such as education, health services, financial resources, and modern technologies. Only in this way can improving access to energy contribute effectively to full economic and social development.

Chapter 23 details policies that, among other things, seek to combine policy design and governance with social and market forces in ways that effectively advance access to energy. While certain types of policies can be applicable in many different cultures and environments, at different levels of technological adoption and economic development, it is often the case that policies need to be tailored to these specific conditions.

This is why Chapter 23 includes an array of policies and a degree of regional disaggregation in its policy prescriptions.

Examples of focused policies that combine a balanced role for government and markets include the following:

- For extension of electricity access into rural areas, a process that involves competitive bidding for state or utility subsidies can improve the chance that these will be used to maximum effect. For rural electrification, Chile developed a program in which subsidies were allocated on the basis of the maximum grid extension that would be achieved for a given amount of money. A similar program exists in Argentina called the Proyecto de Energías Renovables en Mercados Rurales (PERMER). These programs were intended to provide electrification to very isolated communities.
- Modest public and non-government support can help small rural businesses and rural households increase their access to energy investment financing. A frequently cited example is the Grameen Bank of Bangladesh, whose energy division, called Grameen Shakti, lends money for energy-related projects, such as solar home systems that involve installing photovoltaic solar panels to provide electricity in locations without access to an electric grid.
- Innovative institutional arrangements may be able to improve the efficiency with which electricity firms operate in developing countries, especially where the traditional, centrally-managed state electric utility lacks support within the local community. Unpaid bills and electricity theft are particular problems that have been reduced by establishing greater local control over management of the local distribution system. An example is rural electric cooperatives in Bangladesh, called Palli Biddyut Samitee.

When considering energy access, electricity is often the focus of attention. But there are also dramatic benefits from access to clean cooking and heating fuels for the poorest people in the world. Poor indoor air quality from open combustion of solid fuels is still a major source of human morbidity and mortality, especially among women and children who tend to have the highest level of exposure to these emissions (Chapter 4). Today, governments in many developing countries have programs that support in some way – e.g., education, technology subsidies, technical training – the shift from household combustion of solid fuels in open fires to cleaner and more efficient use of commercial fuels, like kerosene and liquid petroleum gases (LPGs, such as propane and butane). To this end, governments may directly subsidize cleaner gaseous and liquid fuels or the acquisition of stoves that use them. Or, government might directly subsidize the acquisition of stoves that still use solid fuels like coal and biomass, but without deleterious emissions that effect indoor air quality.

Thus, many African countries have programs to make LPGs and kerosene more easily available in rural and peri-urban areas and also to distribute improved charcoal burning stoves. If successful, such programs have the combined benefits of reducing time spent gathering biomass, reducing the environmental impacts of excessive exploitation of biomass, and improving indoor air quality with major benefits for human health, especially for women and children.

Box 22.1 | Free Basic Electricity Program in South Africa – Alison Hughes

Free Basic Electricity (FBE) was introduced in South Africa in 2003 to complement an aggressive electrification program (refer to Chapter 19). The policy was implemented after it was realized that poor households were using less than 50 kWh of electricity each month (DME, 2003a). FBE allows poor households with a legal connection to use 50 kWh of electricity each month at no cost. It has the effect of reducing the cost of a kWh of electricity and providing a safety net for consumers.

A challenge with the FBE policy lies in identifying recipients of the allocation. FBE is implemented by distributors, mainly through a blanket allocation to households consuming less than a certain quantity of kWh each month (DME, 2003a).

Pilot studies undertaken after FBE was first introduced have shown that the subsidy typically raised electricity use for lighting and other uses, allowed a more continuous use of electricity by households, and lowered the household energy bill. In this way, it can be seen as very effective. However, on average, the use of electricity increased by less than the subsidy amount of 50 kWh (DME, 2003b), which implies that poorer households continued to use alternative fuels for thermal services.

Criticism of the implementation of the policy is that it excludes many low-income households because families living in backyard shacks or whose homes are situated on land not zoned for settlement cannot receive the subsidy. It can also be argued that the policy should be extended to allow households access to units of any type of energy. This would benefit households by allowing them to purchase a fuel of their choice for cooking at a lower cost to society (Howells et al., 2005).

Box 22.2 | Bagasse-based Cogeneration in Mauritius – Stephen Karekezi

A clearly defined government policy on the use of bagasse, a by-product of the sugar industry, for electricity generation has been instrumental in the successful implementation of the cogeneration program in Mauritius. Plans and policies have been worked out over the last decade for the sugar industry in general. First, in 1985, the Sugar Sector Package Deal Act (1985) encouraged the production of bagasse for the generation of electricity. The Sugar Industry Efficiency Act (1988) provided tax incentives for investments in generation of electricity and encouraged small planters to provide bagasse for electricity generation. Three years later, the Bagasse Energy Development Programme (BEDP) for the sugar industry was initiated. In 1994, the Mauritian government abolished the sugar export duty, an additional incentive to the industry. A year later, foreign exchange controls were removed and the centralization of the sugar industry was accelerated. These and other measures are summarized in the following table.

Table 22.1 | History of Bagasse Policy in Mauritius.

Year	Policy initiatives	Key objectives/Areas of focus
1985	Sugar Sector Action Plan	– Bagasse energy policy evoked
1988	Sugar Industry Efficiency Act	– Tax free revenue from sales of bagasse and electricity – Export duty rebate on bagasse savings for firm power production – Capital allowance on investment in bagasse energy
1991	Bagasse Energy Development Programme	– Diversification of energy base – Reduction of reliance on imported fuel – Modernization of sugar factories – Enhanced environmental benefits
1997	Blue Print on the Centralization of Cane Milling Activities	– Facilitated closure of small mills with concurrent increase in capacities and investment in bagasse energy
2001	Sugar Sector Strategic Plan	– Enhanced energy efficiency in milling – Decreased number and increased capacity of mills – Favored investment in cogeneration units
2005	Roadmap for the Mauritius Sugarcane Industry for the 21st Century	– Reduction in the number of mills to six with a cogeneration plant annexed to each plant
2007	Multi-annual Adaptation Strategy	– Reduction from 11 factories to four major milling factories with coal/bagasse cogeneration plants (Belle Vue, FUEL, Medine, and Savannah) – Bio-ethanol production for the transport fuel markets. Spirits/rum and pharmaceutical products, e.g., aspirin – Commissioning of four 42 MW plants and one 35 MW plant operating at 82 bars - Promotion of the use of cane field residues as combustibles in bagasse/coal power plants to replace coal

As a result of consistent policy development and commitment to bagasse energy development in Mauritius, the installed capacity of cogeneration power has increased over the years. In 1998, close to 25% of the country's electricity was generated from the sugar industry, largely using bagasse. By 2001, of the total electricity supply in the country, 40% (half of it from bagasse) was electricity generated from sugar estates. It is estimated that modest capital investments, combined with judicious equipment selection, modifications of sugar manufacturing processes to reduce energy use in manufactured sugar, and proper planning could yield a 13-fold increase in the amount of electricity generated from sugar factories and sold to the national Mauritius power utility.

Bagasse cogeneration has delivered a number of benefits, including reduced dependence on imported oil, diversification in electricity generation, and improved efficiency in the power sector in general. It is available 100% of the time as long as bagasse production is in place, thus enhancing Mauritius' energy security. Bagasse, as a waste product, can lead to environmental problems such as fire hazards and methane emissions, which are considered potent greenhouse gases, if it is not disposed of properly. Thus, its use for power generation delivers significant local environmental as well as climate benefits. In addition, carbon dioxide produced by bagasse-based cogeneration is minimal, so it is considered a carbon-neutral option.

Cogeneration in Mauritius benefits all stakeholders through a wide variety of innovative revenue-sharing measures. The cogeneration industry has worked closely with the Government of Mauritius to ensure that substantial benefits flow to all key stakeholders of the sugar economy, including the smallholder sugar farmer. The equitable revenue sharing policies that are in place in Mauritius provide a model for emulation in ongoing and planned modern biomass energy projects in Africa. By sharing revenue with stakeholders and the small-scale farmer, the cogeneration industry was able to convince the government – which is very attentive to the needs of the small-scale farmers as a major source of votes – to extend supportive policies and tax incentives to cogeneration investments.

Box 22.3 | Government Assistance Programs for Shifting from Traditional to Advanced Technology: Solar Water Heating in Barbados and Brazil – Lawrence Agbemabiese

Government assistance programs are needed to catalyze transitions to cleaner energy technologies. This is particularly true of developing countries where poorly developed market mechanisms consistently fail to bring critical financial and economic systems into proper alignment with new technological windows of opportunity (Kaufman and Milton, 2005). A brief comparative assessment of solar water heating (SWH) initiatives in Barbados and Brazil lends credence to the view that government assistance programs are critical for replicating successful models of clean energy transitions – beyond the current handful of developing countries where this has happened.

Barbados boasts one of the highest per capita rates of SWH system ownership in the world, with more than 35,000 installed systems serving close to 40% of all households. A very active government SWH incentive program, sustained over a long period of time, is one of the main factors responsible for this achievement. In 1974 "an informed Prime Minister … seeking ways to reduce oil dependency" of the country presided over the promulgation of the Fiscal Incentives Act (Perlack and Hinds, 2003). The Act exempted SWH raw materials, such as tanks and collectors, from the 20% import duty, effectively lowering the cost of installing a system by 5 to 10%. Simultaneously, the Act placed a 30% consumption tax on conventional electric water heaters. In 1980, an income tax amendment provided for the deduction of the full cost of a SWH installation. Though suspended briefly in 1993 as part of structural reforms, the deduction was reinstated in 1996, allowing homeowners to deduct up to 3500 Barbados Dollars (US$1750) per year to cover solar water heaters, among other home ownership costs (Perlack and Hinds, 2003). These tax incentives were paralleled by a government policy of procuring SWH systems for public buildings and publicly funded projects. This combination of incentives and programs achieved the desired result of triggering and accelerating demand for SWH in the country.

In contrast, the absence of such active and direct government support for the SWH industry in Brazil is associated with a relatively low rate of penetration of SWH systems in its energy market. The government does offer some tax incentives to households that purchase and install renewable energy technology, but these incentives are insufficient to bring SWH systems within the reach of the majority of Brazilian households, especially in poorer districts. With 20 years of experience and a large network of manufacturers, distributors, and retailers, Brazil has significant opportunities to dramatically increase the rate of SWH penetration. Compared to the case of Barbados, what is missing in Brazil appears to be the right set of end-user financing solutions backed by deliberate government assistance programs targeting poorer households.

Barbados, and a growing number of developing countries where solar thermal systems are becoming commonplace, share one thing in common: a history of strong political support, expressed through consistent market-transformative policies favoring technologies tailored to local needs. For solar water heaters, the more effective measures have included (re)structuring building and construction codes specifically designed to create or expand markets, building manufacturing capacity of local enterprises for certain components, and creating new financial incentives for suppliers and consumers.

While there are no doubt other factors at work, it is hard to deny the role government policy, including direct assistance programs, have played in some developing countries in the transition to cleaner energy technologies.

22.2.2 Develop Capacity for Energy Transitions

Whether the focus is the provision of electricity or access to cleaner fuels, a critical issue is the extent to which a given jurisdiction has the social, cultural, technical, financial, and institutional environment to develop, adopt, and sustain desired technologies and energy forms. This is why GEA devotes Chapter 25 to the issue of capacity development. Our treatment here is limited to a brief discussion of key issues for policy design.

Evaluations of failed efforts to rapidly expand energy access in developing countries suggest that these efforts foundered in part because of inadequate attention to capacity building in both developed and developing countries. Key elements of capacity development include general education, technical training, trade and cooperative associations that support an array of energy technologies and services, effective financial institutions that support a diversity of corporate sizes and organizational arrangements, a trusted legal system, innovator rights, and protection for investors. Addressing these fundamental necessities will lay the foundation for a transition to a more sustainable global energy system.

Societal efforts to shift the energy system to a different technological trajectory can benefit from a systems perspective that conceptualizes energy systems as socially embedded and historically shaped by the habits, practices, and norms of the actors within them. As new renewable energy technologies emerge in niche markets or are introduced in new environments,[1] earlier institutional frameworks and standards can raise barriers that slow the process of energy transition, as illustrated by case studies of distributed energy systems, off-grid energy solutions, and current practices in patenting (Geels, 2002; Martinot and Birner, 2005; Jacobsson and Lauber, 2006; Bergek et al., 2008).

The long term nature of energy transitions implies that capacities at the actor and systems level will change over time. Change in capacity requires feedback, flexibility, and complementarity in the design of strategies and policies for energy transitions. It demands an openness to new approaches in the formulation of legal and institutional frameworks that stimulate the development and diffusion of renewable and cleaner energy technologies, and closer attention to building capacities needed for continuous learning and innovation. Capacities that enable users, innovators, and policymakers to access knowledge and information, evaluate choices, build coalitions, and limit the negative impacts of change are critical components in an energy transition process.

To assist in this process, Chapter 25 introduces the "capacity matrix" as a tool for conceptualizing capacity development from a broad, systemic perspective. This perspective looks at habits and practices of the actors, existing norms, policies, and standards, as well as technical skills and access to information that impact on energy transitions. The capacity matrix is used to highlight the range of capacities needed in technologies, such as smart grids, small hydro for off-grid environments, wind power, and biodiesel from algae. The matrix is applied to analysis of capacity building in case studies throughout Chapter 25.

Policies for capacity development thus emphasize the dynamics of change in energy transitions, based on the capabilities, habits, and practices of all actors affecting the energy system. This is true not only in the case of helping developing countries accelerate their adoption of clean, efficient energy supply and use technologies, but also in the case of helping industrialized countries with the profound transition that is required for a more sustainable energy system. To this end, Chapter 25 includes a degree of regional disaggregation in recognition of the fact that there is no one-size-fits-all strategy for capacity development, but rather that efforts must be tailored to specific attributes of a given continent, region, country, and even sub-national locales.

22.2.3 Enhance Energy Security

While energy access emphasizes the provision of energy to individual households and communities, energy security is primarily a national-level concern focused on the uninterrupted provision of nationally vital energy services at affordable prices. As argued in Chapter 5, the transport and electricity sectors are key for all countries, whereas residential heating and industrial energy are important for many. Current energy security strategies are often focused on ensuring uninterrupted supply of forms of energy appropriate for these few sectors: liquid fuels for transport, primary energy sources and infrastructure for electricity generation, and various forms of energy for the residential and industrial sectors.

While some energy analysts argue that markets can provide sufficient energy security, others point out that in many contexts long-term security is a public good that can be "undersupplied," even by perfectly functioning markets. For example, in the absence of government regulations, markets often do not ensure adequate investments in spare generation capacity, overall system reliability in the face of extreme natural events, or may tend to favor procuring energy from politically less-reliable suppliers.

Chapter 5 distinguishes between different types of energy security concerns:

- systemic risks inherent in the design and operation of energy systems, including availability of resources, reliability of energy infrastructure, and rapid growth in energy demand;
- risks associated with control over energy resources and threats of hostile actions; and
- unexpected risks which more resilient systems are better able to withstand.

1 The concept of "newness," as used here, includes technologies that are new to a country, region, or user, though they may not be new to the world.

Governments can address these security and reliability concerns with a number of instruments and strategies. To address systemic risks, system design and operation should focus on reducing the likelihood of major system failures. Because this type of risk is internal to the system, governments have a large role to play in ensuring that their own domestic energy system is reliable. In this sense, these are domestically-managed risks. An electric grid, for example, should be designed to have reliable reserve capacity, regular maintenance of existing facilities, and an economically justified level of back-up generation and transmission systems to reduce the chance of system failure.

Energy demand management and forecasting is an important component of ensuring that energy supply expands at a pace that matches the growth in demand. Because energy supply facilities frequently require large investments and a long time to complete, energy forecasts should extend at least a decade or two into the future. While individual energy companies – e.g., electric, oil, natural gas – are usually active in forecasting, government should also play a role in providing a forecasting framework with assumptions about its own investments and energy needs, plus a means of coordinating the forecasts of these different entities. An aggressive energy efficiency strategy can also slow the pace of demand growth, which eases timing pressures on new supply investments.

In the case of non-electric energy demand, various requirements for domestic stockpiling of energy supplies – e.g., storage facilities for oil, natural gas, and coal – and for easier access to energy imports in the case of a failure of one component of the delivery infrastructure – such as multiple pipelines, transmission interconnects, and port facilities – can all contribute to reducing structured reliability risks.

Longer-term systemic risks are often associated with the availability, accessibility, and acceptability of primary energy resources on the national, regional, or global levels, and may be addressed by switching to more abundant, accessible, and acceptable energy resources. In some cases such a switch would mean from non-renewable fossil fuels to renewable energy sources, but this depends on the relative abundance of resources in a given location. In all changes, the decision of government to foster a particular energy source should only be taken after a risk-based economic assessment of such a strategy. In some cases, the costs of reducing structural risks are not justified by the benefits they may provide.

With respect to risks from foreign actions, some governments pursue energy self-sufficiency in order to increase energy security by fostering development of domestic energy supplies. This is an approach that European and the United States governments have debated from time to time (Kalicki and Goldwyn, 2005). But efforts of these countries pale in comparison to the commitments made in the policy that Brazil has pursued since the late 1970s, when it launched a strategy of substituting domestically produced vehicle fuel from sugar cane for oil imports, which it perceived as too costly and volatile. Again, such a decision should be supported by risk-based economic analysis. While this was an implicit aspect of the Brazilian decision, a more explicit analysis can make the policy decision more apparent. Of course, policies, such as that of Brazil should be assessed on the full range of potential implications, including, in this case, macroeconomic effects and environmental impacts at local and global levels.

Energy self-sufficiency can be exercised at the sub-national or local level as well. Thus, many cities throughout the world, in both developed and developing countries, are pursuing decentralized energy strategies that involve greater energy efficiency – in buildings, land use, and infrastructure – with more local supply of energy. The latter may entail, for example, small-scale, urban cogeneration of power and heat for local distribution, on the one hand, and on-site solar power for electricity, water heating, and space heating, on the other. While this strategy is generally not intended to eliminate risks from external disruptions, it can reduce the degree of vulnerability to such risks.

Another strategy for addressing risks from foreign origins is through increasing national control over imported energy resources. For example, Chinese national energy companies pursue acquisition of oil-related assets and companies around the world as a way to increase leverage over the international oil market and secure oil supplies to China. The United States maintains a large military presence in the Persian Gulf region and off the coast of West Africa to minimize the risks of hostile actions against oil production and trade. Needless to say, such ambitious strategies are only available to a handful of major economies and their net benefits are not certain.

Another strategy of increasing control over energy imports is "multi-sourcing" energy supply to minimize dependence on a single source or a particular region, and/or long-term, fixed price supply contracts to protect supply sources from price instability. For example, various pipelines (Nabucco, Nord Stream, etc.) proposed and constructed to link natural gas deposits in Russia and Central Asia to European markets are intended to increase the diversity of supply routes and energy exporters, thus minimizing the consequences of potential disruptions of any one export source or transit route.

Various international institutional arrangements may also increase energy security. These range from long-term bilateral supply contracts – especially prominent in the Eurasian natural gas market – to multi-national institutions and protocols for coordinated action. The latter include the Organization of the Petroleum Exporting Countries (OPEC), which aims to stabilize oil markets and returns to oil producing countries, the International Energy Agency (IEA), established in 1974 by the Organisation for Economic Co-operation and Development (OECD) countries to coordinate oil supply strategies, and the European Energy Charter Treaty, which focuses on diverse forms of energy traded in Eurasia.

Box 22.4 | Strategic Oil Reserves – David Victor

Over the three decades since the Arab oil embargo of the early 1970s, most of the large oil-consuming nations have accumulated substantial strategic oil reserves. The United States alone has spent nearly US$50 billion in today's money to build and maintain a huge strategic stockpile of crude oil. Other large oil importers – notably in Europe and Japan – have also spent heavily to accrue their own reserves. Large new oil consumers, notably China, are in the early stages of building strategic reserves.

In theory, a well-coordinated system of oil caches can provide a buffer against harmful shocks to the world oil market, which makes them important tools of economic policy as well as elements of an effective foreign policy. In theory, oil importers can use their reserves to prevent exporters from brandishing the oil weapon when markets are tight while also making their economies less vulnerable to trouble along critical supply routes, such as the straits of Hormuz, through which about one-third of all the world's oil exports travel.

Because oil is a fungible global commodity, making effective use of oil reserves requires international coordination. That logic inspired the creation of the International Energy Agency (IEA), an arm of the OECD, in 1974. IEA is a forum for governments to discuss energy policy and, in crisis, to coordinate release of strategic oil and other emergency measures.

IEA members have drawn up contingency plans to release strategic oil at critical times, such as the eve of the 1991 Gulf War; in anticipation of the calendar rolling over to 2000 and causing unknown computer glitches that could affect energy supplies; shortly after September 11; and in the aftermath of Hurricanes Katrina and Rita in 2005. IEA members actually collectively released strategic oil reserves twice: two and a half million barrels per day in 1991 and two million barrels per day for 30 days in 2005. Like most deterrents, strategic oil reserves are rarely used in practice.

Historically, all IEA members have been drawn from the ranks of OECD membership. But the rise of emerging economies as large oil consumers – notably China, which is building its own oil reserve – is forcing IEA members to find new more flexible ways to engage countries outside the OECD.

Today's oil market is very different from the one that existed when governments created oil reserves and had more direct control over the quantity and price of oil. Today, oil prices arise through trading on complex financial markets, and this new market has led to calls for changing the systems for managing oil reserves and treating them akin to the array of other financial instruments that governments manipulate as part of economic policy.

Source: Victor and Eskreis Winkler, 2008.

Finally, robustness and resilience concerns are addressed through preparing for supply disruptions in order to minimize their impacts. All IEA members stockpile oil to protect against short-term supply disruptions. Natural gas is also stored in an increasing number of European states. Oil importers, such as European countries and Japan, levy high taxes on oil, which serves to decrease the oil intensity of their economies as a cushion against the macro-economic effects of oil price volatility.

22.2.4 Manage Energy-related Market Power

The conversion and delivery of energy is capital intensive, requiring huge investments in finding, extracting, developing, processing, transporting, and retailing. Capital-intensive sectors of the economy are often associated with a degree of market power, meaning that one or a few firms have considerable influence over the market. Market control by one firm is a monopoly. Market power held by several firms in concert is an oligopoly. Capital-intensive activities are frequently associated with economies-of-scale. For instance, a large facility or company can provide energy at lower cost than several smaller companies. In certain cases, these economies-of-scale foster natural monopolies (utilities), where vesting a single firm with monopoly service provision is the lowest cost option for society, resulting in that service being provided by either a public monopoly or a regulated private monopoly (Berg and Tschirhart, 1988).

With grid networks, as in the delivery of electricity, natural gas, and district heat, natural monopoly conditions are common. In many other settings that are potentially competitive, such as oil and natural gas extraction, high capital intensity and strategic political and economic considerations sometimes lead governments to countenance market dominance by a few large firms or even just one state-owned firm. Likewise, industrial activities that exhibit strong economies-of-scope – meaning that a firm producing one good or service is well-positioned to be the low-cost producer of related goods or services – can result in market power for just a few corporations. In sum, sectors that exhibit significant economies-of-scale, economies-of-scope, and oligopolistic conditions create difficult decisions for governments about the level of public intervention and effort in establishing market competition in society's best interest.

22.2.4.1 Electricity Sector

For most of the last century, conditions that favored monopolies were assumed to exist in various components of the electricity sector. Governments have responded in various ways.

In some cases, governments created publicly owned electric utilities. This strategy often reflected the fact that governments were the only entities willing to bear the risks associated with the construction of electricity networks in remote regions and linking distant sources of supply and demand. This strategy has also rested on the assumption that state-owned corporations would operate with the interests of the public in mind, although there has always been a concern that such corporations can become powerful entities unto themselves, unresponsive to broader public goals and perhaps poorly managed.

In some cases governments have allowed private ownership by a single, monopoly utility, one that is regulated by government or an independent utilities commission to set tariffs and approve major investments. Under the conventional utility commission, cost-of-service regulatory approach, the commission conducts public hearings in which the utility must justify, sometimes in great detail, the prudency of its investments. If approved, the commission will allow the utility to set rates that should, if the firm is effectively operated, enable it to recover its costs plus a return on investment that reflects the risks it faces.

These systems have generally worked where applied, notably in the United States and a few other power markets such as Hong Kong. But regulated private utilities are sometimes wary of taking risks with new technology, and regulators face difficulty in getting the information they need to play an effective role (Viscusi et al., 2005). Concerns have also been raised that this regulatory approach leads to overinvestment in basic infrastructure but lacks incentives for making improvements to operating efficiency (Stigler, 1971). As a consequence, utility regulators are moving toward performance-based ratemaking, an approach that does not limit the rate of return between rate hearings. This encourages the utility to continuously pursue profit maximizing efficiency gains, which the regulator will only translate into lower customer rates after a considerable period of profit-taking by the utility – five years or perhaps longer.

Governments might redesign the network to separate parts of the energy supply chain that are amenable to competition from those where a monopoly is optimal. In the 1990s, most governments that tried to apply market forces did so by restructuring (Newberry, 1999). They unbundled the generation of electricity and often also the sale of electricity and gas to final consumers (where markets might be able to operate satisfactorily) from transmission and distribution (where competitive markets are often impractical).

The last two decades of attempts to restructure electric power systems, accompanied in some countries by a shift from central state ownership and planning toward a greater role for private entrepreneurship, is a useful period for exploring the larger questions of how energy systems and economies can be organized. The mixed experiences with electricity sector reform over the last two decades have shown the dangers, in some cases, of allowing assumptions about the inherent performance of markets to dominate real-world evidence about the special characteristics of a complicated industrial sector like electricity.

As part of separating generation from other components of the electricity system, restructuring advocates have called for the unbundling of generation assets into enough individual entities with separate ownership – private firms, municipal governments, cooperatives, and perhaps some retention of state ownership – that electricity supply competition might be possible. At the same time, the grid system would remain a monopoly in most cases; that is, independently regulated if owned by private firms. This model of electricity reform would comprise the following elements (Joskow, 2006):

- vertical separation of competitive market segments from regulated segments;
- horizontal restructuring of generation to ensure effective competition;
- horizontal integration of transmission and network operations and designation of a single system operator;
- creation of spot energy and operating reserve markets for real-time system balancing;
- unbundling of retail tariffs to separate competitive from regulated costs and prices;
- creation of independent agencies for regulating the network prices and services, including access; and
- establishment of transition mechanisms to deal with unforeseen challenges of reform.

The electricity system in England and Wales is considered to have been very close to this textbook model, and the reforms there have functioned fairly well according to most – but not all – independent experts (Joskow, 2006). However, reform efforts in some jurisdictions have been associated with major problems in terms of supply reliability and price stability. California's electricity crisis of 2000–2001 stands out as an extreme example. In California, wholesale prices were manipulated upward by some electricity traders in the spot market while local distribution utilities were not allowed to increase retail rates correspondingly. The traders were able to bid high prices for providing power, as they took advantage of supply shortfalls related to an exceptional number of units shut down for maintenance and low hydropower supply with low water conditions on the west coast of North America restricting supply. High wholesale prices combined with retail prices capped by regulators caused a rapid increase in debt of distribution utilities, and the supply shortages caused localized blackouts. While the California electricity crisis had many root causes, one was poor policy design that made it nearly impossible to enter into long-term contracts for power, which were more competitive than the short-term spot market, and the reluctance of federal regulators to intervene in the marketplace to stop short-run supply and price manipulation (Wolak, 2003).

There is still no widespread agreement about the optimal form for the electricity market. In any case, opposing ideologies and the diversity of electricity systems in different jurisdictions will ensure continued diversity of market designs. Nonetheless, some issues and lessons are generally recognized. In particular, the electricity sector has characteristics that impede and even prevent development of the degree of competition found within many more conventional commodities. There will thus continue to be an important role for the independent regulation of transmission systems, and even a role for the regulation of investment, pricing, and operation of some parts of the generation system. This regulation is necessary to:

- prevent spot market manipulation;
- ensure adequate short-run reserve capacity;
- ensure adequate investment in new generation supplies;
- determine optimal transmission capacity and operation;
- ensure transmission access for all eligible suppliers, including small-scale renewable energy; and
- promote coordination between electricity systems to maximize efficiency and reliability.

Policies for managing the electricity sector have generally focused, as does the above discussion, on the potential for integrating some degree of competition into electricity generation and retailing in large grid systems. However, in developing countries, and even in rural areas of developed countries, there are areas where isolated mini-grids are the norm and will, in fact, become more important in the future. Proper management of these systems is also necessary and requires different management strategies (Victor and Heller, 2007).

22.2.4.2 Oil Sector

There is a close relationship between the policy response to natural monopoly markets and the policy response to other forms of market power. Many of the market concerns in energy supply arise not only when monopolies reign, but when competition is imperfect, often because of the very large size – and capital commitment – in the energy industry, and also because many energy services are priced in global markets where it is difficult to ensure true competition. OPEC members agree to constrain their collective output in order to stabilize international oil prices at levels above those of pure competition. Because they collude overtly, this type of oligopoly is commonly referred to as a cartel. More conventionally, oligopoly exists in markets where a few firms dominate, with opportunities to collectively behave like a monopoly even without the overt collusion practiced by OPEC members.

There are many other settings in which such collusion could arise and governments organize to oversee the market and restore competitive outcomes. Oil refining and distribution have often been seen as activities with sufficient economies-of-scale that an oligopoly would develop in place of more aggressive competition. Anti-trust action can help ensure a competitive marketplace. Where that is not possible or is ineffective, governments may regulate prices to approximate those of relatively competitive markets, although other considerations, such as national economic performance, may also be important.

In the oil sector at the global scale, there has been a significant shift toward state ownership of oil companies. Indeed, today, most of the world's largest oil companies are owned by governments and trace their origins to decisions by governments to assert control over oil revenues by creating state-controlled oil companies, in many cases because they did not trust private enterprise, much of it foreign-owned. The experience to date is that these national oil companies vary widely in performance and strategy, and they also vary enormously in ability to actually meet the goal of government to exert greater control over the oil sector. National oil companies are also discussed in the following section on the management of valuable energy resource endowments.

Box 22.5 | Electricity Market Reform in Australia – Brian Fisher

In Australia before the mid-1990s, the electricity supply chain, comprising generation, transmission, distribution, and retailing, was owned and managed either by government monopolies spanning the entire chain, or by monopolies at the generation and transmission stages linked to monopoly businesses operating in the distribution and retailing sectors, usually with a franchised "catchment" of customers.

The ownership and management structure provided a protected environment for the industry and there were various indications that electricity was not being provided at least cost. A government-commissioned report released in 1991 cited "poor investment decisions" and "gross overstaffing," as well as reserve plant margins well above international standards, as indicators of inefficiency within the industry (Industry Commission, 1991). This and other factors spurred a wave of disaggregation, privatization, and corporatization, as well as the establishment of an interconnected market in parts of Australia and the introduction of retail contestability for the majority of consumers.

In the southern and eastern states of Australia – where networks are now interconnected – a central initiative of reform was the creation of a common electricity market. The market was managed by NEMMCO (now the Australian Energy Market Operator [AEMO]), a company established in 1996 and owned by the relevant state and territory governments. Broadly, NEMMCO resolves the supply schedules of generators with the demand schedules of purchasers to create a spot price for electricity. It then issues dispatch orders to generators indicating how much they are to produce, taking account of capacity constraints and likely transmission losses. In terms of retailing, even the smallest consumers of electricity in areas covered by the common electricity market have a choice of retailer, with the exception of those in Tasmania, where full contestability was expected by 2010. Western Australia and the Northern Territory are too far from the integrated market in eastern Australia to take part, but Western Australia has operated its own wholesale electricity market for the south-west of the state since 2006.

Most elements of transmission and distribution have not been opened to competition on the grounds that these stages have "natural monopoly" characteristics. Each state has a monopoly transmission business, and has either adopted or retained a framework whereby distribution within a region is generally handled by a single entity. Some entities have interests in both distribution and retailing.

Average labor productivity across Australia in the generation sector had more than doubled by the time the majority of deregulation reforms were underway or completed in the late 1990s. There were also significant reductions in the wholesale price of electricity. Modeling by the Australian Bureau of Agricultural and Resource Economics suggested that annual gross domestic product would be US$2.9 billion higher (in 2008 dollars) in 2010 than it would have been had electricity market reform not been undertaken (Short et al., 2001).

Box 22.6 | South Africa's Institutional Failures and the Power Crisis – Alison Hughes

There is widespread consensus in South Africa that December 2007 heralded an era of crisis in the South African electricity industry. December and the following months were characterized by rolling blackouts. For the first time in South African history, large users such as gold mines lost their electricity supply for extended periods. The underlying cause of the crisis is an inadequate reserve margin. After a long period of excess capacity, the reserve margin was allowed to drop to 6% in 2007 from 31% in 1994. While there are periods where load shedding is not necessary, it will be many years before an adequate reserve margin is restored and electricity supply stabilizes.

The reasons behind the crisis are complex. Short- and medium-term causes can be traced back to a decision to restructure the electricity sector in 1998, which involved breaking up the state monopoly utility Eskom into competing generation companies. At the same time, government wanted to encourage independent power producers to enter the market, and placed a moratorium on Eskom building new generating capacity. A new institutional framework was prepared, but in 2004, government performed a policy u-turn and announced the scrapping of the restructuring program. The rationale was two-fold: (1) government wanted state-owned enterprises to play a larger role in national development; and (2) no private investment was forthcoming for new capacity, since neither a market system nor a framework for concluding long-term power purchase agreements was put in place. Eskom was given the go-ahead to bring a new peaking plant online and mothballed coal plants are being returned to service, but no new generation units were scheduled for operation before 2012.

Another underlying cause behind the crisis was the long-term prevalence of ultra-low electricity prices, which were below long-run marginal cost and fell in real terms during the 1990s. South Africa has always relied on low-cost energy to attract energy-intensive industry and foreign investors, and has pursued a long-term policy of low energy prices. The national regulator continued this trend by keeping electricity price increases close to, or below, inflation, reflecting the average cost of Eskom producing the electricity. The pricing policy was in part due to significant over-build of generating capacity by Eskom in the 1980s, partly funded through an indirect subsidy from the country's Reserve Bank. Through the pricing policy, demand-side management and energy efficiency were dis-incentivized, load grew faster, and new investment in generating capacity was deterred.

22.2.5 Manage Valuable Energy Resource Endowments

In some countries, the natural endowment in valuable energy resources, especially conventional oil and natural gas, are of such a magnitude that energy is one of, if not the, most important sectors in the economy. As experience has shown, however, a spectacular energy resource endowment can be both a blessing and a curse. On the one hand, the revenues from the resource can allow governments to provide high levels of social services like education, health care, and welfare. On the other hand, the resource windfall can produce so many challenges, as mentioned earlier, that analysts sometimes refer to this endowment as a resource curse (Collier, 2007).

Sarraf and Jiwanji (2001) note several factors leading to resource curse type outcomes. Higher returns to investment and labor in the resource sector can cause capital shortages and wage inflation that harms other sectors of the economy, even though these other sectors would otherwise have wealth-generating potential long after the demise of a non-renewable resource like oil and natural gas. This resource dependency may be inconsequential if the resource is slated to last a century or more. However, it is extremely important in cases where the resource will be largely depleted within just a few decades.

Resource price volatility can cause great uncertainty in government revenues. Periods of high prices tend to be associated with expansion of government expenditures and borrowing, while periods of low prices are associated with cutbacks in government activity and the accumulation of debt.

Periods of high resource prices can also be associated with the rapid expansion of the resource sector itself, which can overheat an economy, in either industrialized or developing countries, and affect the competition for labor and capital with other sectors – referred to as "Dutch disease" – and also create pressure to develop the resource more quickly than should occur from a sound technological perspective. In addition, rapid development and export puts an upward pressure on the exchange rate, which, in turn, makes it more difficult for other sectors of the economy to compete, both internationally and domestically. Developing a resource too quickly can lead to wasteful resource exploitation. An example would be to develop oil and gas reservoirs at accelerated rates that result in lower recovery of the resource than could have been achieved by development at a slower pace.

The wealth generated by a valuable energy resource is an inducement to corruption, where unscrupulous public officials and representatives of domestic and foreign firms vie for resource rents (Leite and Weidmann, 1999). This activity can be so widespread that the distribution of resource wealth to the public at large is far below what it should be, with perhaps even a negligible benefit. Even without pervasive corruption as an outcome, it is relatively easy for ineffective governments to garner political support by distributing some of the rents to key interests and thereby avoid more rigorous oversight of governing institutions (Sala-i-Martin and Subramanian, 2003). Although it need not be the case, a society with a resource windfall can actually be worse off in terms of its economic health and the strength of its social fabric than it otherwise would have been without the resource.

Governments that have successfully handled resource endowments have done so by developing various policy instruments and strategies to address the special challenges of managing energy and mineral resource wealth to the benefit of current and future generations. Some lessons are outlined below.

Governments should not use the resource rents for excessive energy subsidies to domestic consumers, but instead maximize the return from resource assets, in both domestic and international markets. Thus, domestic energy would be sold at international prices. The rents from the domestic and export sales of the resource can then be distributed to citizens as improved public services and infrastructure or even as direct resource rent payments, which is more economically efficient – and usually more equitable – than a strategy to return the rents via large subsidies to domestic energy users.

Governments can pursue some degree of economic diversification, but should only do so where there are sound prospects for the sustained development of alternative activities. There are many unfortunate examples of governments using windfall resource revenues to subsidize economic development initiatives that have no hope of standing on their own once the subsidy is later withdrawn. But there are also examples of governments helping innovative domestic firms to develop niche markets in activities that are related to resource extraction, which can be marketed internationally, or in completely new industrial activities where the country can have a comparative advantage once it passes the initial start-up hurdles.

Governments should establish mechanisms that reserve a significant share of the revenue from the resource for the future. Obviously this strategy is more affordable for rich countries – for example, Norway and its oil and gas resource revenues – or for countries with a huge resource endowment relative to the size of their population, such as the United Arab Emirates with its large oil revenues relative to its population size. The revenue that is set aside should be invested cautiously in trusts or sovereign wealth funds that are diversified to reduce the risks of wealth depletion via exchange rate shifts or mis-investment.

Governments should establish mechanisms that allow them to access some of the accumulated surplus when resource prices are low. For example, a stabilization fund would not be money set aside for future generations, but would instead be a fund that grew during times of relatively high resource prices but which government could use to sustain key levels of services during times of low resource prices. This would reduce volatility in government expenditures that would otherwise have resulted from volatility in resource prices. However, while this approach seems sound, it is difficult to apply in practice. It is impossible to know in advance when prices are above or below their long-run average, since technological change and/or resource depletion could mean that the long-run price trend in the future will be very different in an upward or downward direction. Only with hindsight can governments determine the extent to which their strategy was providing a proper counter-cyclical balance of building up and drawing down surpluses from the resource.

Governments should create mechanisms that provide transparency in all transactions involving government officials and resource firms in order to minimize the risks of resource-motivated corruption. This objective can be advanced by legislating open accounting systems that enable watchdog organizations like Transparency International to put pressure on large, multi-national oil and gas companies to "publish what they pay" in dealings with national oil companies and governments.

Governments can create mechanisms by which part of resource revenues are returned directly to communities located in the resource areas, in part to compensate for negative effects of resource development, but also to give communities a stake in the efficient extraction of the resource and to maximize the revenues it is capable of generating.

Many oil-rich countries capture much of the economic rent associated with this high-value endowment by having national oil companies play a key role in the sector. The rents appear as profits for these companies. However, a well-designed system of resource rent taxation is important, even in cases where public ownership is predominant, because this provides transparency as to the economic value of the resource. Resource rent taxation should also not be limited to oil. Coal, natural gas, and even favorable hydropower sites can all be associated with substantial resource rents. Countries with a long experience of resource rent taxation tend to have evolved toward rent collection mechanisms that combine ex ante and ex poste obligations. In other words, companies submit competitive ex ante bids for rights or access to the resource – mineral rights, exploration rights, hydropower sites, wind farm sites – and then, during production, also pay a percentage of total revenue or net revenue.

Box 22.7 | Oil Funds – Carolyn Fischer

The Norwegian experience with oil funds is often held up as a best practice for the way a country should manage the revenues it generates from the production of oil. In Norway, the vast majority of resource revenues are transferred to a Petroleum Fund, which is used to generate income and diversify risk by investing exclusively in foreign bonds and equity. As a small, open economy, Norway would not be able to absorb the oil revenues into its own economy, so it has chosen to maintain its existing tax structure and save the wealth for future needs, such as funding the social security system. This strategy contrasts with that of Alaska, which uses most of its oil revenues to fund state government expenditures and keep taxes low. The rest is invested in the Alaska Permanent Fund, which generates dividend income for all citizens of the state.

For developing countries, current needs are arguably more pressing than future ones. High-return strategies then involve investing in human capital and critical public infrastructure, rather than equities, with the caution not to invest beyond the absorptive capacity of the economy or to protect unsustainable businesses. Botswana, a major diamond exporter, represents a success story in this sphere, where the primary mechanism of revenue management is not an explicit savings fund or allocation scheme, but rather a solid approach to budgeting. The multi-year National Development Plan process aims to stabilize government spending growth and to prioritize spending. The focus has been to expand essential public services and infrastructure – e.g., electricity, water, roads, police, health care, and education – and to provide credit to state-owned enterprises, which, in turn, have made commercial loans. At the same time, the government has accumulated international reserves and earmarked budget surpluses for stability spending in leaner years, and it has managed liquidity and the exchange rate to avoid real appreciation.

In other countries, development benefits of resource extraction have been elusive. In response, some companies have engaged directly in development and compensation programs to improve community relations. Overall, good governance seems a necessary component for resource riches to become a broad-based economic blessing, and not a curse.

Source: Fischer, 2007.

Box 22.8 | Resource Rent Taxation – Brian Fisher

The concept of economic rent is outlined in many places, but in this context the definition given by Stiglitz (1996) is most pertinent. Under competitive conditions, the economic rent accruing to a mining firm is the difference between its revenue and its costs, where costs include a "normal" return to capital – the minimum return needed to hold the capital in the mining activity. Economic rents may persist in the mining industry because there is not a perfectly elastic supply of non-renewable resources.

Brown (1948) proposed a tax that is calculated as a fixed proportion of net cash flow each year, where net cash flow is defined as the difference between revenue and total costs. Total costs include all capital expenditure during the particular year but exclude interest payments. In years when "rent" calculated in this way is positive, the government receives a fixed proportion of that rent. In years when the mining company incurs a loss, the government would rebate a fixed proportion of that loss.

The characteristic that distinguishes the resource rent tax proposed by Garnaut and Ross (1975) from a Brown tax is that there is no provision for the government to pay a rebate on losses. Instead, losses may be carried forward, and increased by a "threshold" rate of interest, until they can be deducted from future profits. Taxation is then triggered when the net cash flow from the project is positive. In cases where future profits are insufficient to offset past losses, then the private firm will bear those losses.

The rate of resource rent tax applied in the Australian petroleum sector, for example, is 40%. Although many of the profit-based royalty systems in place around the world are not good approximations to a pure resource rent tax, it is interesting to note that in most cases the tax rate is set below 15% (Otto et al., 2006).

22.2.6 Reduce Environmental and Human Health Impacts

As discussed in Chapters 3 and 4, humanity is increasingly aware of the impacts and risks to the environment and human health from energy supply and use, including indoor air pollution, local and regional air pollution, pollution in fresh water and oceans, direct damage to landscapes and ecosystems, and the major transformation of the earth's climate, with its own implications for weather, ecosystems, coastlines, human economies, and human health. In assessing these effects, some analysts find it helpful to distinguish between "extreme event risks," on the one hand, and "ongoing impacts and risks," on the other.

Extreme event risk refers to events that have an extremely low probability of occurrence but could have an extremely severe impact. Examples include a large oil spill from an ocean tanker, a major refinery explosion or gas leak, or severe radiation exposure from a nuclear accident. Policymaking for extreme event risks can be especially challenging because people tend to focus on the severe consequences of the event itself and forget to consider the very small likelihood of the event (Bier et al., 1999). Nuclear power experts, for example, often express frustration with the public's fixation on the potential human impacts of a nuclear accident while seemingly accepting a much higher ongoing rate of human harm from coal combustion (Matysek and Fisher, 2008).

Ongoing impacts and risks, like the risk of coal mining accidents, refer to operational occurrences that are fairly well understood and accepted as part of the regular impact of a particular activity. The amount of land alienated by an open pit coal mine is easily known. The impact of acid emissions on natural systems, infrastructure, and buildings is quite well understood. Scientific understanding of the impact of greenhouse gas emissions on the earth's climate has improved significantly over the past few decades, although there is still considerable uncertainty about the magnitude of temperature changes associated with different GHG atmospheric concentrations. In fact, because of this uncertainty, GHG emissions present both ongoing impacts and well-understood risks, but also an extreme event risk – runaway global warming. This extreme event has a low probability, but it is not low enough for an increasing number of experts and policymakers (Stern, 2006; Weitzman, 2009).

Ongoing impacts and risks from a particular activity can affect land, air, and water, although some effects are concentrated in one particular medium. A key challenge is balancing and mitigating these effects, as no energy source is completely free of environmental impacts.

On land, impacts and risks are associated with the exploration, extraction, processing, and transportation activities in fossil fuel mining and production, uranium mining and production, and renewable forms of energy like biomass, hydropower, wind, and solar. Specifically, these impacts include open pit coal mines, the well-dotted landscape of an oil and gas producing region, the land required for energy biomass plantations in agriculture or forestry, the land flooded for major hydropower dams, and land required for transmission lines and other networks. As humanity increasingly turns toward renewable forms of energy, land use conflicts arise also for the siting of wind power and run-of-the-river hydropower facilities.

In the air, emissions from the combustion of fossil fuel products and biomass have local, regional, and global impacts. Incomplete combustion of refined petroleum products and biomass leads to indoor emissions of carbon monoxide, black carbon, and volatile organic compounds, in addition to methane leaks, all of which can impact human health. Improved combustion will reduce these emissions and normally also reduce GHG emissions, since these are either direct or indirect GHGs.

In water, there are threats from fossil fuels to ground water, rivers, lakes, and oceans from urban runoff, urban sewage, permitted industrial effluents, and industrial accidents, including oil spills in fresh water and oceans. Discharge of water used for cooling in thermal power plants, including nuclear plants, leads to thermal pollution of waterways. Air emissions from coal-fired generation can lead to acidification of lakes and elevated mercury levels in fish and other aquatic life. Hydropower development, including small-scale, run-of-the-river hydropower, can disrupt rivers and the life systems they support.

The diversity of these threats calls for a multiplicity of policy instruments, the choice of which depends on which medium is under threat and whether the source of the threat is local, regional, or global (Kemp, 1997; Jaffe et al., 2002; Harrington et al., 2004; Newell, 2008; Wei and Rose, 2009). The introduction of this chapter laid out a broad list of government policy types. This range is narrowed somewhat to the following list for discussing options for energy-related environment policy. These include:

1. information programs that inform firms and households of the environmental benefits and perhaps personal financial benefits from certain types of investments and behavior, such as energy efficiency, an approach that extends to sweeping campaigns of public education and engagement;

2. financial penalties (emissions pricing) that discourage rather than prohibit emissions;

3. subsidies that promote changes in investment and behavior by firms and households;

4. regulations that prohibit certain activities, technologies, or energy forms, or that regulate in ways that provide some degree of market incentives for innovation and adoption of more sustainable energy technologies, such as tradable quota obligations or tradable emission permits; and

5. direct actions by governments and their agencies at all levels to fund public sector R&D, upgrade public buildings, facilities, and equipment, improve infrastructure, and develop social capital, such as education, training, etc.

22.2.6.1 Information Programs and Public Engagement

Information programs promote environmentally beneficial energy choices by using both moral suasion and financial self-interest arguments. Moral suasion arguments might focus on global or local environmental benefits for current or future generations. Financial self-interest arguments might convince firms to promote "greenness" as a way of gaining or sustaining market share. Or, with better information about energy use rates and costs, firms and households might realize that some investments, like energy efficiency and conservation, may provide a financial gain over the long term. The challenge for information programs is to compete with all other sources of marketing information, much of which ignores the environmental and even long-term financial benefits of certain energy supply and demand choices and most of which now tries to convince consumers that all of their choices are "green."

One of the challenges is policymakers may assume that information programs can be effective on their own in stimulating a voluntary shift toward profoundly different technologies. Governments in OECD countries have relied to a large extent on information programs to incite actions by firms and households to make choices that affect environmental performance, but these have been considerably less effective than hoped for (Karamanos, 2001; Khanna, 2001). One of the lessons, in the case of climate policy, is that information on its own – without supporting emissions pricing and regulations of technologies and fuels – is unlikely to drive technological transformation toward lower carbon emissions. Recognition of this reality has shifted the thinking of policy advisors toward finding ways of combining policy options so that information programs work in concert with other, more compulsory types of policies. At the same time, some advocates of this approach emphasize the need for wide-ranging campaigns that engage key interest groups and sectors of the public – for instance, youth, rural inhabitants, etc. – in attempts at profound perceptual and behavioral change, and to increase the acceptability of stronger policy instruments, such as carbon taxes or cap-and-trade systems.

22.2.6.2 Emissions Pricing

Policies like emissions taxes, tradable emissions permit prices, or other types of financial charges seek to provide a price signal that reflects to some degree the value of the impacts and risks to the environment and human health from various types of emissions and effluents. Taxes and other charges can also be applied to specific technologies, such as inefficient vehicles or batteries, where the revenues can be used to fund recycling and the disposal of toxic materials.

Decades of price elasticity studies by economists support the argument that emission taxes can be an effective policy for environmental improvement. Economists also point out that emissions pricing is the most economically efficient policy and that this approach also scores well in terms of other policy criteria, such as administrative feasibility. Yet it is politically difficult for policymakers to implement the level of emissions pricing that would cause the kind of price changes necessary to drive profound technological change in the necessary time period. In some cases, therefore, emissions pricing may need to work in concert with other policy options.

Sweden deserves attention in this context. Emissions of carbon dioxide have dropped by 8% over the years 1990–2007, while GDP grew over 40%, largely as a result of the introduction of carbon taxes in 1990 that, among other things, drove changes in fuel use for district heating away from oil and toward woody biomass.

22.2.6.3 Subsidies

This policy approach was first discussed in the section on energy access, where it was noted that governments have subsidized: (1) electric grid extensions to provide access to electricity for rural and remote areas; (2) the prices of electricity and fuels, such as kerosene, as poverty reduction schemes; and (3) certain technologies like low emission stoves. Subsidies are also applied to energy supply innovation (R&D), commercial development and dissemination of favored technologies, and energy forms for strategic or economic development reasons, such as nuclear power, new fossil fuel production technologies like offshore oil and unconventional oil, and renewables like hydropower and, more recently, wind and biofuels.

With the growing concern for climate change, however, the rationale for some types of subsidies has been questioned. The effect of research and production subsidies on the international price of a key commodity like oil is difficult to estimate. But since high-cost oil production technologies, like the tar sands in Canada, have received such subsidies in the past, there is reason to presume these have had a downward effect on the international price of oil and therefore an upward influence on GHG emissions. In contrast, the effect of subsidies to fossil fuel consumption is easier to estimate. These subsidies existed in many countries a few decades ago, and were especially notable in the countries of eastern Europe and the former Soviet Union. Today, such subsidies remain in other non-OECD countries – such as OPEC members – to provide lower prices, especially for gasoline and diesel. They also exist in non-OPEC developing countries to help certain customer groups, such as the subsidized price of electricity for farmers in India. The IEA (2010) estimates that, globally, the subsidies to fossil fuel consumption exceeded US$300 billion in 2009, and that reductions in these subsidies could lower fossil fuel consumption and associated GHG emissions by 5%.

While energy access is still seen as a legitimate reason for targeted and temporary energy use subsidies, there is now wider recognition that such subsidies should be aligned with policies for GHG abatement. This means that subsidies for fossil fuel consumption should be phased out and subsidies might only be allowed when they either foster non-emitting forms of energy or energy efficiency.

Indeed, subsidy programs for energy efficiency have been significant in OECD countries, especially in the electric sector. Electric utilities in the United States alone spent over US$20 billion on electricity efficiency in the two decades from 1985 to 2005. However, as with information programs, hindsight evaluations of subsidy programs for energy efficiency have increasingly challenged the efficacy of this type of non-compulsory policy. In the case of energy efficiency, for example, it can appear on the surface that each high efficiency device acquired with the help of a government or utility subsidy contributes to a more efficient energy system. However, this can be deceiving.

First, a certain number of higher efficiency devices are acquired even in jurisdictions without energy efficiency subsidies, as some technologies naturally evolve toward more efficient models. Anyone who would have purchased an efficient device anyway, but nonetheless receives a subsidy, does not actually increase the efficiency of the energy system from what it otherwise would have been – a business-as-usual trajectory. These subsidy recipients are therefore called "free riders," and their participation rate must be subtracted before the true effectiveness of the subsidy policy is known. Economists and policy analysts also use the term "adverse selection" to explain this problem.

Second, the acquisition of a more efficient device may provoke a rebound effect, which is a feedback between improvements in energy efficiency and the demand for energy services. Researchers have described various components of the rebound effect (Sorrell et al., 2009). To simplify the discussion, these are compressed into direct and indirect rebound effects.

With the *direct rebound effect*, energy efficiency investments lower the energy operating costs of energy-using buildings and equipment, which may lead to greater use. This response may occur even if the efficiency investment is not profitable; it is simply a demand response to lower operating costs. If, however, the efficiency investment is also profitable, then it increases net income. Expenditure of this additional income may cause increases in demand for the original energy service. Thus, profitable efficiency investments can induce substitution and income components of the direct rebound effect.

The *indirect rebound effect* refers to second-order developments induced by energy efficiency. The literature describes various components of indirect rebound. For simplicity, we focus on three:[2] (1) by lowering energy demand from what it otherwise would be, energy efficiency should decrease the price of energy, which could increase demand for some energy services; (2) profitable energy efficiency investments increase income, which could increase the demand not just for the original energy service, as noted above, but also for other energy services; and (3) innovation and adoption of energy-efficient technologies for a given energy service could provide spillover effects that increase the demand for other uses of energy, some of which could be completely new.

This third form of indirect rebound warrants elaboration. In essence, improvements in the productivity of a factor of production are normally associated with increases in demand for that factor. Thus, labor productivity gains are associated with increased demand for labor. Fouquet and Pearson (2006) provide an energy example by tracing the historical relationship between productivity gains in lighting services and its demand. They note that in the United Kingdom since 1800, the cost of lighting services fell to one-three-thousandth its initial level while per capita use grew by 6500 times. Although this correlation does not ensure causality, there is a strong likelihood that the dramatic drop in the cost of lighting that resulted from efficiency gains played a not-insubstantial role in the rising demand for lighting services over time. Thus, improvements in the efficiency of basic lighting technologies may accelerate the emergence of and demand for related energy services like decorative lighting and security lighting, just as improvements in the efficiency of refrigeration technologies may accelerate the emergence of related energy services like wine coolers, water coolers, portable freezers, and desktop fridges.

While all researchers can agree with the concept of rebound, there has been considerable debate about its significance and its empirical measurement can be difficult and controversial. The reason is that changes in the cost of energy services caused by energy efficiency would be just one of many factors determining the demand for energy services during a given period. The Fouquet and Pearson (2006) study, noted above, demonstrates a correlation between lighting productivity gains and the demand for lighting. These productivity gains no doubt had a role in increased per capita demand for lighting in the 200 years since 1800 in the United Kingdom. But incomes rose dramatically during this time also, raising the question of the relative importance of rising incomes versus falling costs due to productivity gains in causing the increased demand for lighting. Some research papers or special issues of journals have tried to assess the magnitude of direct and indirect rebound effects (Sorrell et al., 2009; Schipper, 2000). In general, these surveys have given inconclusive results, but suggest that some energy end-uses are more prone to rebound effects than others, and that direct rebound effects are not particularly large for most energy services, but that indirect rebound effects could be very large over long time periods, including the development of new, but related, energy services.

Research into free riders and rebound effects with energy efficiency policies suggests that these can be quite substantial, indicating that subsidy programs too may need to be combined with other more compulsory policies like emissions pricing and technology and fuel regulations (Loughran and Kulick, 2004; Gillingham et al., 2006; Arimura et al., 2009). Finally, subsidy programs have administrative costs and these too need to be considered in the cost-effectiveness calculation, although increasingly utilities and even some governments are now doing this.

Short-term subsidies also suffer from the question of timing. Since energy-using devices are durable goods, firms and consumers can accelerate or delay purchases they would make anyway to coincide with the timing of the subsidy. This shifting behavior increases the cost relative to the benefits of one-off subsidy programs, like the recent "cash-for-clunkers" program in the United States and other countries. Even subsidies that are renewed can suffer from the perception of intermittency. In the case of the United States, production tax credit for renewable electricity generation, uncertainty about policy renewal is compounded by uncertainty about profits, since positive income is required to take advantage of the tax credit.

Given these issues with subsidies when used on their own, one strategy that policymakers are turning to is a combination of subsidies and taxes. For example, some jurisdictions have experimented with vehicle fee bate schemes, in which high emission or high fuel consumption vehicles pay a tax and this revenue is used to provide a subsidy to low emission or low fuel consumption vehicles. The subsidy, while still subject

2 The literature is not consistent. Some of the indirect components described here are sometimes described as direct rebound effects. And sometimes, the income effect on a given energy service, which is ascribed above to direct rebound, is considered to be part of the indirect rebound effect.

to free-riders, helps with political acceptability, while the tax may have more of an effective role.

Even without help from taxes, subsidies can be effective if substantial and well targeted. One of the most compelling recent examples is the "feed-in electricity tariff" that has enabled several European countries to rapidly increase the role of renewables like wind power in the generation of electricity. This tariff guarantees a higher price for electricity from renewables and therefore provides stable revenue projections that help independent power producers secure financing and adequate capital.[3]

Subsidies are also a means by which industrialized countries can transfer funds to developing countries in order to assist in the transformation toward a more sustainable energy system. Foreign assistance in the form of low interest loans to develop fossil fuel, nuclear, and hydropower resources has been provided for decades by governments and international agencies like the World Bank. With the growing concern for climate change, however, new mechanisms have been created, such as the Global Environment Facility and the Clean Development Mechanism, the latter as part of the Framework Convention on Climate Change. These types of subsidies are discussed later in Section 22.2.8 on sustainable energy policy coordination at the international level.

22.2.6.4 Regulations

In some cases, regulations as a policy instrument can be strongly prescriptive in nature, such as an outright ban on a technology or resource use. Concern for the risks of an extreme event, like a nuclear accident, has led some governments to prohibit the development of nuclear power. The potential for nuclear weapons proliferation has prompted some of the world's major powers to use trade threats and technology embargoes to hinder the development of nuclear power by other countries. Concern for the loss of land and harm to migratory fish from large hydropower developments has led some governments to ban such projects, and even to dismantle some existing hydro dams.

Most countries regulate to some degree particulate and gas emissions from the combustion of fuels, including both fossil fuel products and biomass. Energy efficiency standards are applied in most countries to regulate appliances, buildings, vehicles, and industrial equipment. Regulations that affect the safety of oil tankers, petroleum refineries, and transmission lines are also commonplace.

Regulations are sometimes applied in flexible ways in order to reduce the cost of compliance by allowing exchanges between those subject to the regulation. One type of market-oriented regulation is an emissions cap-and-trade policy. A cap is set, with penalties for non-compliance, as with other regulations. The cap is allocated – freely or by auction – in the form of permits or allowances and, because these are tradable, the trading price provides a price signal to emitters, just like an emissions tax. Each emitter has the option of reducing emissions, and selling surplus allowances to other emitters, or not reducing emissions and instead purchasing the needed allowances from someone else.

There is considerable debate about the relative merits of cap-and-trade versus emissions taxes. Cap-and-trade provides greater certainty about the emissions outcome of the policy. This is seen as desirable from the perspective of ensuring the realization of an environmental objective. In contrast, emissions taxes provide greater certainty about the effect of the policy on energy prices faced by firms and consumers. This is seen as desirable from an investment and economic efficiency perspective. Emissions taxes are likely to be much more stable than emissions prices that emerge from the market in which emissions permits are traded. In reality, however, it is possible to design cap-and-trade systems with a price floor and price ceiling and to allow banking and borrowing of emissions permits in order to reduce the tendency for emissions price volatility.

Another type of market-oriented regulation is an obligation to achieve a minimum market share of a particular good or production process. An example is a low-emission standard for vehicles that obliges producers to achieve a minimum market share for the sale of a desired type of vehicle, with an allowance for producers to trade among themselves to achieve the aggregate minimum sales requirement. Similarly, a renewable portfolio standard in electricity sets minimum market shares for renewable electricity generation, with credits for producers to trade among themselves in achieving the aggregate target. Effectively, these policies combine a subsidy for renewable energy with a tax on non-renewable energy generators.

22.2.6.5 Direct Action by Government

While the policies discussed thus far mainly involve governments trying to induce alternative behavior and technology choice by firms and households, there are also opportunities for governments to take direct action. Senior levels of government invest in R&D and can establish funding criteria that emphasize environmental and human health objectives, especially with respect to energy-supply and -use technologies. All levels of government own buildings, vehicles, and equipment, and they can require specific technological choices in terms of environmental and human health impacts. Governments can even use their purchasing power to influence the commercialization choices of manufacturers. Thus, public procurement strategies can make major equipment acquisitions contingent upon the ability of one or more competing manufacturers to produce new technologies that meet aggressive targets for energy efficiency or low environmental impact.

Local governments determine land use through planning, zoning, and building, permitting authority provision of public transportation options

3 It is important to note, however, that subsidies come from somewhere. If they are provided by government, they are generated mostly through taxes elsewhere in the economy. Conversely, they may be provided as cross-subsidies from other customers or industry.

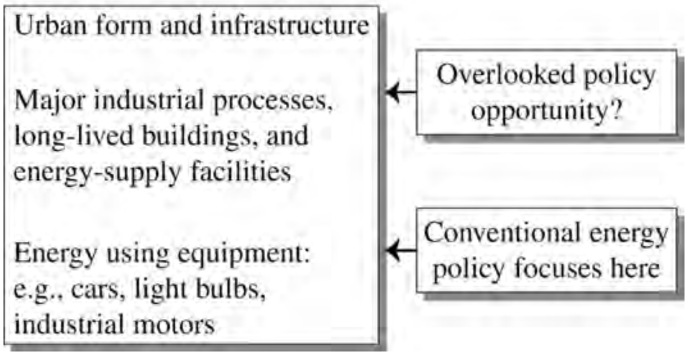

Figure 22.1 | Hierarchy of energy-related decision-making. Source: Jaccard et al., 1997.

within and between urban centers, responsibility to help energy utilities site transmission and other network lines, and urban and regional control over zoning and development. An example in this area is the rising interest in community energy management, an effort by local government especially to coordinate regulations and land use decisions affecting building and facility characteristics, siting of buildings, and infrastructure investments in ways that minimize the use of energy, maximize synergies between systems, and provide opportunities for the greater use of energy forms that are more environmentally benign.

Figure 22.1 shows a hierarchy of energy-related decisions. While energy policy has traditionally focused on the buildings, industrial facilities, and equipment in the middle and lower part of the hierarchy, it is increasingly recognized that there is considerable opportunity for municipal and sometimes more senior levels of governments to influence the evolution of urban form through land-use zoning, development permitting, siting requirements, building codes, and infrastructure investment in public transportation, district energy, and even urban liquid and solid waste collection and disposal systems. Decisions at higher levels of the hierarchy are more often taken by government, given its ultimate control over land use and major infrastructure. Also, decisions at higher levels tend to have longer-term impacts. The rate of turnover of urban form is much slower than that of vehicles or the equipment used inside buildings. This makes policies affecting the top of the hierarchy all the more urgent, given the rapid transformations that are required for a more sustainable energy system.

A final consideration is that many environmental impacts and risks cross international borders, which can make it extremely difficult to create effective policy because this requires that many countries coordinate their objectives and efforts to achieve multi-national or global public good. Depending on their level of economic development and resource endowments, countries could have very different perspectives. China is less interested in reducing coal use in order to reduce GHG emissions than is a country such as Japan, which, unlike China, is poorly endowed in terms of coal resources. The challenge of achieving a coordinated international effort with respect to the environmental impacts of energy supply and use arose in the 1980s with the cross-border challenges of acid rain and the control of acid emissions. Europe and North America made headway on this challenge, but the focus has now shifted to the need for international coordination of GHG emissions control. This special problem is addressed in Section 22.2.8 below on energy policy coordination at the international level.

Box 22.9 | Key Policies for GHG Abatement: Cap-and-trade Versus Carbon Tax – Mark Jaccard

When addressing an environmental externality like GHG emissions, economists have a preference for policies that provide a single price for GHG emissions from all activities in the economy. Thus, economists' two favorite policies are either a tax on emissions or the allocation of rights to a fixed quantity of emissions. In the latter case, tradable emission allowances are allocated by auction or a political process, perhaps reflecting historical emissions and other criteria. In any given period, those who have reduced emissions enough to hold a surplus of allowances can sell them to those who find it cheaper to purchase these instead of fully reducing emissions to match allocated allowances. Borrowing and banking of some allowances may also be permitted. The combined effect is that the market for tradable allowances, if it covers all emissions in the economy, would provide an economy-wide price signal in the same way as would an economy-wide GHG emissions tax.

The two policies differ in that the emissions charge provides price certainty while the emissions cap provides quantity certainty. The former gives investors confidence about the future price of emissions, but it leaves uncertain for government the actual emission reductions that will be induced by a given tax level. The latter gives certainty to government about the level of future emissions, but the price of tradable permits will be uncertain.

There are vigorous debates about the relative merits of these competing approaches (Weitzman, 1974). In practice, however, they may not end up that different. The level of emission taxes is uncertain to the extent that governments will inevitably adjust taxes as they observe the reductions induced by a given level of tax. And emission caps may be implemented in conjunction with price floor and price ceiling strategies that increase confidence about the price while reducing certainty about the future level of emissions. Also, governments may apply caps to industry but taxes to other sectors of the economy.

While taxes and caps are usually discussed in terms of national or regional application – a regional example being Europe – the global nature of the climate risk has led to debate about which approach is best from a global perspective. The Kyoto Protocol is based on the idea that countries can negotiate national caps and then establish allowance-trading mechanisms. Critics of this approach claim that it will be less difficult and more effective to apply harmonized carbon taxes around the globe rather than trying to extend restrictive caps from the Annex I countries of Kyoto to all countries on the planet (Nordhaus, 2007).

While taxes and caps are largely seen as policy substitutes, there is a fairly widespread belief that dramatic GHG reduction by mid-century requires the combination of a tax or cap policy with additional policies that accelerate the rate of technological change. One such policy is the allocation of large public subsidies to the initial developments of new capital-intensive technologies, such as the first full-scale CCS systems, the prototypes of new nuclear power systems, and technological innovations that provide reliable energy storage for renewable energy. Another policy is the use of regulations to guarantee market shares for new and emerging technologies that otherwise have higher costs than conventional, GHG-emitting technologies. An example is the renewable portfolio standard, which guarantees a growing share of the electricity generation market for renewables.

Box 22.10 | Information as a Policy to Influence Sustainable Energy Choices – Charlie Wilson

Information policies have been widely used to promote the adoption of sustainable energy technologies as part of broader behavior change strategies. Through the 1980s and 1990s, for example, United States utilities spent over US$20 billion providing information and incentives in response to a perceived shortfall in both households' and firms' knowledge of widely available and cost-effective investment opportunities.

Information-based approaches to promoting energy technologies remain widely used today, but have been improved by a wealth of empirical findings on the "who," "how," and "what" of information provision.

Lessons on *who* should provide information and *how* they should provide it are inter-related. Information disseminated from person to person, particularly if such people are trusted peers or social role models, is more effective at changing behavior than information spread through mass media channels. The perceived trustworthiness and credibility of the information provider is also important. So too is consistency. Clearly inconsistent policies weaken the credibility and thereby effectiveness of information – e.g., policies to reduce energy prices vs. information policies on cost-effective, energy-efficient technologies.

The *what* of information provision relates to form and content. "Folk" behavioral models that describe how people actually think about energy clearly demonstrate the importance of information that is simple and salient; i.e., it stands out in some way and is easily comparable. Efficiency ratings on product labels can be a good example of this. Targeted or otherwise personally-tailored information is also effective. In contrast, information that is technical, detailed, factual, and comprehensive is often glazed over, or interpreted subjectively and selectively, often to support pre-existing beliefs.

Another important role for information is to provide feedback on behaviors undertaken or technologies adopted. The transition underway from aggregated monthly utility bills to real-time energy use monitors enabled by smart metering will greatly improve the value of information as feedback on energy-related behavior: consider the analogy of being informed of your total food expenditure once a month, as opposed to receiving an itemized bill each time you shop.

Well-designed information policies may successfully raise awareness and support positive attitudes toward sustainable energy technologies. But the ultimate success in changing behavior is limited by contextual factors. High investment costs, coupled with limited access to capital and strong consumer preferences for immediate rather than delayed financial benefits, are a common example. Other contextual constraints include: regulations (e.g., planning guidelines); economic incentives (e.g., falling energy prices, sales taxes); social norms (e.g., larger homes); habits and routines (e.g., daily washing and cleaning); and community governance traditions (e.g., resisting outside developers).

The stronger these contextual constraints, the weaker the effectiveness of information policies. In general, therefore, information policies are effective only as part of a broad and consistent multi-pronged policy framework to promote the diffusion of sustainable energy technologies. As an example, information policies are a useful rapid response to a window of opportunity presented by some external shock, such as rapid oil price rises or supply disruptions.

Paradoxically, the best form of information provision results from peoples' actual experiences, and only comes with widespread diffusion. The communication of positive experiences through networks of families, friends, and peers is the most effective means of supporting social learning, increasing familiarity, forming favorable attitudes, and reducing the perceived risks of sustainable energy technologies.

Sources: Dietz and Stern, 2002; Owens and Driffill, 2008.

Box 22.11 | Community Energy Management and Transportation in Curitiba, Brazil – Mark Jaccard

While the rapid urbanization in developing countries presents monumental challenges, it also provides unique opportunities. A myriad of incremental, and seemingly unimportant, decisions about urban land use and infrastructure taken today will profoundly determine the ability of tomorrow's burgeoning urban centers to achieve sustainable energy systems. Curitiba, Brazil, provides an example of how effective planning can have a positive impact on a community's development, particularly in terms of energy use for transportation.

A city of over two million, Curitiba has, since the 1970s, channeled growth along five axes radiating from the city center. Each axis has a bus expressway and parallel roads for vehicles. Land use zoning has concentrated high-density development to the five axes, especially centered on interchange bus terminals that are located about every two kilometers along each axis. Passengers from lower density areas take feeder buses to these terminals, where they transfer to the express buses for travel to the city center. Costing about 1/200th per kilometer of a conventional subway system, the bus expressway nonetheless achieves comparable performance in terms of ridership and travel times. While Curitiba has a high rate of car ownership for Brazil, almost 75% of commuters use buses, resulting in 25% lower vehicle fuel consumption than similar Brazilian cities. Reduced fuel consumption contributes to the city's relatively low level of urban air pollution, and reduced vehicle use for commuting fosters a more pedestrian-oriented city center. The express bus system is operated primarily by private companies under guidelines from, and in partnership with, the municipal government.

Box 22.12 | Masdar, CCS, and Enhanced Oil Recovery – Michael Ohadi

The United Arab Emirates (UAE) is the world's second largest emitter of greenhouse gas per capita. In 2006, the Government of Abu Dhabi launched an initiative, the so-called Masdar initiative, with a primary goal to promote advanced and clean energy supply and substantial reduction in the CO_2 emissions to the environment.

The Abu Dhabi Government is pumping billions of dollars into the clean energy Masdar initiative with the double aim of capturing CO_2 emissions from major sources of CO_2 production and injecting it into oil reservoirs for enhanced oil recovery purposes. The long-term goal is to prepare the world's third-largest crude exporter country with economic diversification and a future less dependent on a supply of crude oil.

CCS technology refers to the capture of carbon at the source, then compressing and liquefying and finally transporting it by pipelines to safe and permanent storage in geological formations. The nature and size of the reservoirs of Abu Dhabi, as well as the short distance between CO_2 emission sources and oil reservoirs, created an opportunity for a reliable and technically feasible CCS project.

The UAE embarked on the Masdar CCS project and the CO_2 emission reduction program in 2007. The project aims to slash the emirate's CO_2 output by about one-third by 2020. In its first phase, the project aims by the end of 2012 to capture five million tonnes of CO_2 from power plants and industrial facilities and to transport the CO_2 to oilfields for enhanced oil recovery (EOR) applications. Injecting CO_2 in the oil reservoirs will maintain underground pressures, thus resulting in enhanced recovery of the crude oil. EOR is receiving more attention in recent years with further maturing of the oil reservoirs in the country. The world average of oil recovery is estimated at 35%, which in essence means 65% of recoverable oil is being left behind if it is not recovered through advanced technologies, such as use of injected CO_2 and other enhanced oil recovery techniques. Currently natural gas is being injected in some of the Abu Dhabi reservoirs for enhanced oil recovery purposes. It is estimated that over one billion standard cubic feet of natural gas per day is currently being injected into oilfields for enhanced oil recovery that otherwise can be used for power generation or petrochemicals.

The Masdar CCS project has already launched a pilot plant project in which CO_2 is captured from a source and is being injected in one of the oil reservoirs. Data on CO_2 diffusion and its impact on the enhanced oil recovery of the reservoir are being collected. The project involves close collaboration between the Masdar Institute, Abu Dhabi National Oil Company and its subsidiaries, the Petroleum Institute, and other academic and industrial collaborators from around the world.

The project is being developed over a multiphase road map, with the feasibility study undertaken in 2007 and the Front End Engineering Design (FEED) phase begun in August 2008. The fully developed CCS project will use CO_2 from power stations, refineries, and other industrial sources. The following emitters are planned in the first phase of the project: a major power plant, an aluminum smelter, and a steel plant. The combined phase one capacity is five million tonnes of CO_2 per year with an approximately 300-kilometer CO_2 pipeline network to carry the CO_2 to the injection site(s).

Masdar's CCS activities have considerable potential to be expanded in Middle Eastern countries where significant carbon capture potential can be located under the Kyoto Protocol. The Masdar initiative can serve as a role model for similar developments in other Middle Eastern, as well as other regional and industrialized, countries. It is an example of a clean and peaceful energy initiative that has multiple win-win objectives, including utilization of CO_2 for enhanced oil recovery to free up more oil while liberating substantial amounts of natural gas for power production and other purposes, and finally economic diversification and job creation opportunities.

22.2.7 Accelerate the Rate of Energy-related Technological Change

Innovation and technological change are essential contributors to a sustainable energy future. Energy technology innovation is addressed in detail in Chapter 24 and, as noted above, the broader social and institutional capacity on which technological change is predicated is covered in Chapter 25. Below is a summary of the context, rationale, and criteria for policy to foster innovations that are critically needed to address the joint challenges of global environmental change and the energy service needs of all of humanity.

22.2.7.1 Characteristics of Innovation and Technological Change

In its most general sense, technology is a system of means to particular ends (e.g., Grubler, 1998). Technologies comprise both physical creations – plants, equipment, devices – and information and knowledge systems – know-how, skills, experiences. Technology is thus a specific form of knowledge that can be embodied (an appliance) or disembodied (know-how). The respective importance of these two forms changes over the life cycle of a technology from invention through research, development, and demonstration to niche market applications and, ultimately, pervasive diffusion. Through this lifecycle from innovation to deployment, technological knowledge needs to be created, developed, and applied. It can also depreciate or be lost if not actively managed. Innovation policy is therefore fundamentally concerned with stimulating and managing this process of knowledge generation, application, dissemination, and feedback, and thus needs to embrace a systemic perspective (e.g., Carlsson et al., 2002). This includes the continuous feedback between different stages of a technology's lifecycle, which typically characterizes successful innovation processes. Technologies are also inherently dynamic, and the innovation process is characterized by high degrees of uncertainty. This requires adaptive policy approaches that recognize the dynamics of technological change, and allow for experimentation, foster diversity, and accommodate failures.

22.2.7.2 The Rationale for Public Technology Policy

Policy intervention in the innovation process is primarily justified by the public good characteristics of knowledge and thus the potential positive spillovers beyond the innovating agent. Additional sources of market failure exacerbate this public good problem (Jaffe et al., 2005).

New knowledge can be expensive to generate, but cheap to imitate. As a result a "free-rider" problem exists in which private firms under-invest in innovation, as the benefits cannot be fully captured. Without intervention, these knowledge spillovers result in under-allocation of resources to innovation. This problem applies to all technologies, but is exacerbated for energy technologies due to the high capital costs and development lead times, which magnify the risks for innovators, and the potentially limited returns in regulated markets. Literature related to innovation has repeatedly found that social benefits from innovation exceed the benefits accruing to private innovating firms several-fold: social rates of return are persistently and significantly higher than the private returns from innovation (Freeman, 1994). Policy intervention is needed to correct this market failure, particularly as the limited data available on private-sector R&D investment suggests a decline over the last 20 years against an ever-rising backdrop of public concerns on energy security, access, and environmental impacts.

Other sources of market failure increase the need for government intervention. Positive interaction effects may exist in cases where both under-pricing of the environment (lack of pricing or regulation to reflect negative externality costs) and under-pricing of knowledge (positive externalities of information) make the financial attractiveness of innovation investment much lower than its true value to society. Increasing returns, due to network effects and economies-of-scale of incumbent technologies, delay the deployment of nascent technologies, and possibly lead to under-investment at earlier stages in the innovation process. Information asymmetries between technology producers and technology adopters make deployment sub-optimal in early stages when technologies are unproven. Principal-agent problems – for example, between owners and occupants of buildings needing thermal retrofit to improve efficiency – hinder deployment, even after technologies prove to be reliable.

However, successful innovation depends on much more than overcoming market failures. A systemic view on innovation highlights the fact that innovation entails a series of collective, embedded processes involving many actors, networks, and institutional settings that can fail at many different levels and need to be addressed by policy intervention (Hekkert et al., 2007).

22.2.7.3 Policies for Innovation

Policies for innovation can: (1) directly target the innovation process; (2) support the innovation system; or (3) unintentionally impact innovation while targeting an unrelated concern.

Direct policies for innovation vary according to the target and timing during the innovation process. Policy is needed at each stage of this process. The role of government is most evident at the earliest stage

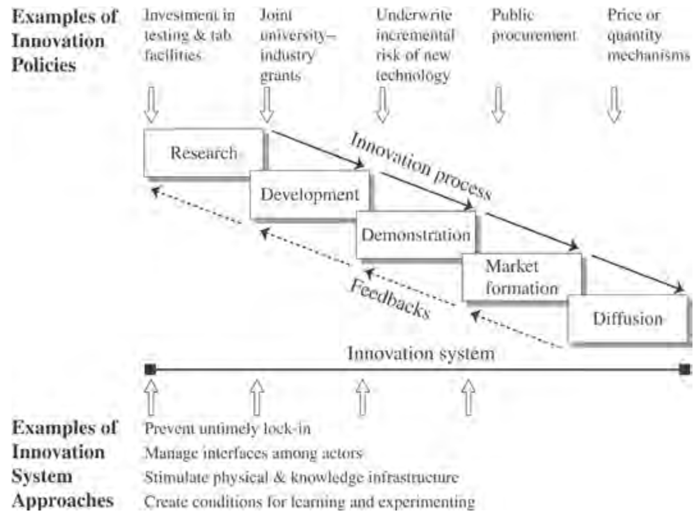

Figure 22.2 | Overview of policies for innovation. Source: developed by GEA authors.

of basic science and research. Together with the private sector, governments are also engines of applied energy R&D. But governments also need to play an important role in leveraging private sector investment at the early commercialization stages by supporting demonstration activities to reduce risks and market formation to underwrite demand.

This innovation process is situated within an overarching system comprising the actors, institutions, and networks involved in developing and commercializing a technology (see Chapter 24 for details). Innovation policies must also target the successful functioning of the innovation system (see Figure 22.2 for examples).

Policies on issues such as education, taxes and subsidies, and market regulation can all exert an important, yet indirect, influence over both the supply of, and demand for, innovations. This reinforces the need for consistency not just between direct innovation policies but also between the broader regulatory and institutional environments for innovation.

Policies supporting the supply of innovations or the development of technologies include investments in R&D, intellectual property protection, laboratory and testing infrastructure, training and skills, university–industry collaborations, formal and informal mechanisms of knowledge exchange, technology roadmaps to guide the direction of innovation, and financial incentives such as tax credits for private investments. Not all innovation, however, derives from formal R&D activities. Problem solving and incremental improvements in existing technologies are also of importance and can be stimulated and supported by public sector policies that lead to the creation of outreach, extension, and technical support programs. Policies supporting the demand for innovations as commercialized technologies include demonstration projects, public procurement, market niche creation (supply obligations), market incentives via changes in relative prices (via environmental taxes or feed-in tariffs), standards and regulations, direct financial support, education, and marketing. These "supply push" and "demand pull" policies are complements and not substitutes. Innovation success stories are typically characterized by comprehensive and consistent policy support through the entire innovation process. Although these criteria can be generalized, particular innovation policies must take into account specific local conditions or be otherwise tailored to the technological or market characteristics of an innovation.

22.2.7.4 Principles for Innovation Policy Design

Selecting innovation policies is necessarily context-specific. However, the literature (Grubler et al., 1999; Norberg-Bohm, 2000; Nemet, 2009) and the sample of energy technology case studies reviewed in Chapter 24 points to a number of guiding principles or policy criteria that are considered generic to all technology domains and adoption environments. These are:

Innovation policies need to be aligned and consistent. This should be true both within a given innovation system and between different innovation systems to maximize spillover benefits. Alignment implies a set of policies that are co-ordinated and free of contradictions. A prime counter-example is the current emphasis of public support for low carbon innovation alongside the much larger subsidization of fossil fuel technologies.

Aligning incentives for energy technology innovation is aided by an explicit and systemic innovation strategy. Such a strategy will inevitably face trade-offs between policy objectives, as is the case with standards and incentives to promote energy efficiency while maintaining downward pressure on energy prices.

Innovation policy frameworks and supporting institutions need to be stable and independent. This is the means of effectively managing the process of technology knowledge generation, application, and maintenance. Independence avoids the resistance to change and learning of the vested interests, which grow up around incumbent technologies. Policy objectives and instruments require continual re-assessment and potential adjustment toward long-term transformative goals.

Stability wards against the eventual loss of knowledge. Erratic policy support and signals can lead to rapid knowledge depreciation. Governments play an essential role in managing expectations of the demand for innovation by providing policy signals that are credible and consistent over a multi-year period to reduce the uncertainty of private sector investments reliant on distant payoffs. Policy instability acts as a barrier to commercial innovation, and can accelerate knowledge depreciation. Stability does not preclude policy dynamism and flexibility to respond to new information. But it does, however, mean patient and consistent goals backed up by predictable funding support for various stages of the innovation lifecycle.

Superior policy requires a commitment to good data. Innovation policy needs to be founded on a clear understanding of how the innovation system operates, what it requires in terms of inputs, and how to assess its effectiveness in terms of outputs. Understanding and assessing innovation systems requires far better data on innovation activities than are currently available. For example, technology-specific private sector R&D data are almost entirely lacking. Systematic and comprehensive information disclosure as a condition of policy support can help redress the current scarcity of reliable innovation outcome data. As an example, subsidies for demonstration projects and niche market deployment could be contingent on documentation and public disclosure of both successes and failures in order to facilitate wider learning.

Policy should support the different stages of innovation, and the feedbacks between them. Traditionally, innovation policies have targeted specific stages of the innovation process while neglecting the essential feedbacks between them. As an example, publicly-funded testing and demonstration facilities for new technologies can ensure disclosure of unbiased performance benchmarks to guide technology R&D. (For example, see the case study on wind power in Chapter 24.) Feedback from market deployment experience can also benefit technology design and manufacturing quality assurance. (See the case study on solar photovoltaics [PV] in Chapter 24.) Increasingly, policies to support information sharing and knowledge feedbacks need to consider the globalized nature of technology markets.

Innovation policies should facilitate widespread experimentation. Successful diffusion is underpinned by knowledge generated through the development, design, construction, and operation of a technology. Inherent uncertainties make this a process of experimentation. Experimentation leads to incremental improvements and learning-related cost reductions, and also underpins the success of increasing unit sizes or overall production volume to capture economies-of-scale. Indeed, the capital intensity, risk, and opportunity costs of many large-scale energy technologies should orient experimentation toward relatively small-scale versions of technologies in a diverse portfolio to reduce the consequence of failure. By comparison, narrowly-targeted policy support for single design large-scale demonstration projects – such as breeder reactors – is high risk.

Experimentation can, and also perhaps should be, multifarious, involving an array of different actors, forms, and stages of the technology's lifecycle. Governments should intervene to manage the natural commercial tendency to rapidly hone in on a dominant design that confers market advantages and potential cost reductions.

Innovation policies need to focus on portfolios rather than single technologies. The magnitude and array of energy system challenges, combined with inherent uncertainty in the innovation process, requires a broad portfolio of technologies. Such portfolios need to balance each technology's option value – or social benefits in case of successful diffusion – and risk, in terms of both innovation failure and investment.

These portfolio decisions will require a combination of expertise from public and private sector innovation actors. Formal scientific tools for innovation portfolio design and analysis are increasingly available, but need further development as well as an institutional home for application.

Generic principles for innovation portfolio design include: (1) incorporate options from across the entire energy system, especially including the traditionally under-researched and under-funded energy end-use technologies, and avoid an overemphasis on any single, "magic bullet" option; (2) manage resource constraints by focusing on granular, less capital-intensive technologies such as end-use innovations and smaller scale supply options; (3) link large-scale, capital intensive, and high risk innovations into global innovation portfolios that enable international coordination and cooperation; (4) avoid pre-empting the outcome of decentralized market-based technology experimentation while counteracting private sector biases toward early selection of a dominant and rapidly scalable technological solution; and (5) promote technologies that show good prospects for gains from learning-by-doing in application and economies-of-scale in production.

22.2.8 Coordinate and Implement International Energy-related Policies

Globalization of the world's economic system is associated, as is to be expected, with the globalization of its energy system. Globalization can have benefits, but it can also present major challenges.

First, globalization of the world's energy system has not had a significant benefit for the poorest people on the planet. The rate of foreign direct investment in the energy sectors in developing countries remains at only a fraction of the level needed if most people in the world are to have access to electricity and modern fuels over the next few decades. Governments have tried to make gains in this direction, in part through collective funding mechanisms like the World Bank and the International Monetary Fund, and in part through encouraging the establishment of domestic environments more favorable to foreign investment. But these strategies, thus far, have not provided the investment funds that are needed. The key issue, from a policy strategy perspective, is to find a way to make globalization work for the poorest people in the developing world.

Oil's price has been set internationally for decades, but now this is also increasingly the case for coal, natural gas, and sometimes even electricity. Globalization of the world's energy system can contribute to increased energy security, widening the options for any given country to meet its energy needs. But globalization of energy trade can also have the reverse effect, especially as individual governments lose the ability to ensure energy supplies for domestic markets at relatively stable prices. For example, while individual governments cannot prevent oil price spikes, like that of 2008, working in concert they may be able to reduce some of the energy price volatility that has occurred in the past.

Finally, when it comes to international energy policy coordination, the issue of climate change is becoming increasingly critical. Addressing the risk of climate change through GHG emissions reductions is a collective public good that can only be achieved with collective action. Most countries, perhaps starting especially with the world's largest emitters and most powerful countries, must work together to successfully reduce emissions. Thus far, the international community has put a great deal of effort into widespread negotiations, largely through the United Nations sponsored Framework Convention on Climate Change, but this has not yet produced truly significant action by those countries who have made commitments, and not yet induced enough significant emitters, like the United States, China, and India, to agree to substantial emissions cuts.

While some see globalization as largely a force for improvement in the world, others see it as the cause of problems and argue that policies should try to prevent or restrain globalization. Still others argue that globalization is inevitable, albeit undesirable, so the only alternative is to work within this reality and not resist it. Finally, some believe that with careful policy strategies, the forces of globalization can play a critical role in addressing the very challenges it presents. More of this latter perspective is discussed in the description of globalization-related policy instruments and strategies.

If globalization is to significantly increase energy access in developing countries, these countries and international agencies need to improve the climate for foreign investment in energy supply while at the same time ensuring that such investment meets the need for clean, affordable energy. Thus, international institutions like the World Bank need to keep reforming the criteria by which they support energy policies, although some significant progress in this direction has already been made in recent years.

If globalization is to enhance rather than reduce energy security in developing and developed countries, significant changes in international energy security regimes will be required. The current focus of energy security institutions such as the IEA and the OPEC on short-term fossil fuel supply stability is both increasingly ineffective – as demonstrated by recent price volatility – and untenable in the face of persistent systemic challenges associated with rapid demand growth and increasing geographic concentration, if not outright physical scarcity, of petroleum resources. Moreover, stability, inherently preferred by energy security regimes, is at odds with the rapid and radical change expected of energy systems to meet sustainability objectives. The future international energy security regimes should therefore be able to overcome these limitations by expanding focus away from the supply-side and fossil fuel orientation of today. They should also be able to provide for a meaningful dialogue between energy importers and energy exporters, including such emerging major energy users as India and China and such major energy suppliers as Russia.

Another key area for international coordination and cooperation is to enhance security measures that prevent the diversion of the peaceful uses of nuclear energy to the production of nuclear weapons by governments or terrorists. While much progress has been made in this direction over the past decades, the challenge becomes all the greater as the number of countries with nuclear capabilities increases (for further information, see Chapter 14).

Of increasingly dominant importance is that two decades of efforts have thus far failed to result in an agreement on the establishment of a global architecture for concerted international action on GHG emissions to address the risk of climate change. Many of these efforts have focused on the creation of international agreements to reduce emissions, notably the 1992 Framework Convention on Climate Change and the 1997 Kyoto Protocol. This top-down approach seeks to achieve widespread agreement among almost all countries, whether they be big or small contributors. In the long run, participation by virtually all countries will be required, if only to prevent the disintegration of agreements by a growing number of free-riders (Barrett, 2003; Aldy and Stavins, 2007). But as a starting point for reaching an international agreement with meaningful commitments and effective policies, some have argued that it may be easier to limit negotiations to a small number of countries that account for most emissions or that have the financial ability to contribute significantly to the global costs of reduction (Victor, 2001). Perhaps in a bottom-up approach, a group of 20 major emitters, like the United States, China, India, and some European countries, or the European Union as a whole, should first try to negotiate targets and policies that could form the basis for an eventual international architecture that other countries would gradually join. Other issues that need to be addressed include the effect of institutions like the World Trade Organization on efforts to achieve a meaningful global effort to reduce GHG emissions.

22.2.9 Key Energy-focused Policies[4]

For the eight previously delineated energy-related policy goals to be achieved, energy services, technologies, and operating practices of the global energy system must evolve in specific directions. Certain outcomes need to occur in terms of energy efficiency, renewable energy, fossil fuels, and nuclear power. These key energy-related outcomes represent the means for achieving the energy-related goals. A survey of the various chapters of GEA, and especially Chapter 17 on scenarios for a sustainable global energy system, suggests four outcomes of particular importance:

- The global energy system needs to become much less energy-intensive for a given level of energy services, i.e., much more energy efficient.
- The global energy system needs to rapidly shift toward renewable sources of energy, used with minimal harm to the environment and humans, such as the need for food production.
- Wherever fossil fuels are used, the environmental and human impacts and risks from their use need to be minimized.
- Wherever nuclear power is used, its energy-related and weapons-related risks to the environment and humans must be minimized.

In this section, generic policies are outlined that offer a means of achieving sustainable energy. In Section 22.3.1, some of the key policies that are likely to be effective in achieving these outcomes are presented. Additionally, Chapters 23, 24, and 25 focus especially on critical areas of policies for energy access, policies for capacity development for energy transition, and policies for accelerating energy-related technological change. The policies in Chapter 22 have been selected because: (1) they have broad applicability in terms of the urgent need for rapid technological and behavioral change; and (2) they have either already demonstrated effectiveness in real-world applications or they appear to perform well against many of the key policy evaluative criteria listed in the chapter. Many of the other chapters discuss policies, especially the ones focused on specific technology and resource options.

For advancing each of these four means to sustainable energy – efficiency, renewable energy, clean fossil fuels, and safe nuclear power – a critical policy challenge is to ensure that valuable innovations successfully navigate the hazardous steps from invention, to commercialization, to widespread market penetration. Thus, while policy support for basic and applied R&D is needed, policy support is just as important in the demonstration and initial commercial phases; when additional support can help lower the production and operating costs of new technologies and establish, or help to establish, market niches that will stimulate investor interest in the technology. Finally, market pull policies are needed to carry the product through to widespread dissemination. The policies listed under each of the four means to sustainable energy, in the following Section 22.2.9.1, cover the various phases of this technology life cycle.

22.2.9.1 Reducing Energy-intensity of Energy Services

As noted throughout GEA, much of humanity requires a dramatic expansion of energy services. For sustainability, this expansion must coincide with a significant reduction in the energy intensity of these services. Even with such a reduction, the global energy system is likely to grow significantly by mid-century as the global population and the per capita energy demand of the billions of people with minimal energy services continues to grow.

A reduction in energy intensity can occur in basically four ways. First, even without a technological change it is sometimes possible to reduce

4 See also Chapters 8–14.

energy use while retaining an energy service at a given level. For example, it is possible to design urban form and land use so that total or average commuting distances are decreased.

Second, there may be cases where people can be helped to find ways in which their quality of life can be sustained even while their demand for certain energy services actually declines. An example would be encouraging people to adopt indoor thermal comfort zones ranging from 18–26°C, with people living in hotter climates allowing warmer temperatures and people in cooler climates allowing cooler temperatures instead of keeping temperatures at a fixed level. Another example would be reduced consumption of meat, since less energy is required to produce most non-meat foods. For an increasing number of people in rich countries, reducing meat consumption is a dietary change associated with improved health.

Third, a shift to more energy-efficient technologies will reduce energy use per capita, everything else held equal. Of course, there is a challenge with more efficient technologies in that they tend to have higher up-front costs and energy service demands will increase (the rebound effect) as the operating costs of providing these services fall. Well-designed policies may be able to reduce this likelihood, which usually involve price changes that reinforce the goal of reducing energy use.

Fourth, a restructuring of the economy toward services, more recycling of materials, and cascading uses of energy, and away from material- and energy-intensive inputs and final products can all help to reduce energy use for a given level of energy services.

The following prominent policies can contribute to these four ways of reducing energy intensity:

- *GHG emissions pricing* in the form of carbon taxes and/or cap-and-trade schemes that raise the price of energy and make it more profitable to reduce energy use;

- requirements that prescribe *community energy management* by municipal authorities, involving coordinated efforts to reduce energy use via land-use zoning decisions, development permits, and siting requirements, and the link to public transportation and other infrastructure planning and development – including an overall goal of reducing the need for private vehicle use, especially in urban settings (transportation demand management);

- *education programs* by governments, utilities, non-governmental organizations (NGOs), industry, the media, academics, and others to foster a conserver lifestyle with respect to energy and material throughputs;

- government *energy efficiency information and subsidy programs* for all types of equipment, appliances, products, and buildings. When efficiency programs involve subsidies, they must be carefully designed and monitored to reduce the likelihood of high free-rider rates, even though some degree of free-riding is inevitable. Revolving green funds for energy efficiency investment can provide a subsidy in the form of low-interest capital that is mostly recaptured through payments by the recipient as their energy bills are reduced through efficiency;

- in the case of electric, gas, heat, water, and sewer utilities, efficiency programs administered by the utilities themselves, called *utility demand-side management*, that might be motivated and applied relatively efficiently by regulations that entail tradable mechanisms, such as tradable energy efficiency performance standards or certified amounts of energy saved (referred to in Europe sometimes as "white certificates");

- *building code* changes that, over a specified time period, set increasingly stringent requirements for new and retrofitted structures in terms of energy use and emissions. This should affect all buildings and structures in residential, commercial, institutional, and industrial sectors;

- *efficiency regulations* that set an aggressive but reasonable phase-out schedule for the market availability of less energy-efficient industrial equipment, household appliances, transportation vehicles, and other equipment;

- *professional training* of architects, engineers, designers, and installation contractors in methods and installation of energy-efficient devices;

- use of *public procurement* and co-operative procurement of energy-using devices as opportunities to create a first market for energy-efficient products and building concepts, or increase the market volume for the best already in the market;

- *funding and encouragement of research, development, and demonstration* of more energy-efficient solutions;

- regulations that prohibit the sale of products and equipment that use energy when not in operation (called *standby power or phantom power regulations*);

- regulations that *limit the use of packaging* in retail sales that has substantial energy implications in terms the cumulative effects of production, distribution, and transportation of goods;

- in addition to increasing the retail price of various forms of energy to reflect environmental costs, utilities should be mandated by government or by independent regulators to establish tariffs that price marginal energy use, such as peak electricity or the last units consumed in a billing period, at its marginal cost of production. This form of *non-linear pricing*, also called marginal cost pricing and time-of-use pricing, tends to provide a further incentive for reduced energy use, especially in jurisdictions where the long-run cost of new supply is higher than the average present costs of operating the electricity system. For residential and commercial customers, this might be associated with the widespread distribution of rates that rise with greater energy use per billing period and/or rates that reflect peak and off-peak costs of service. And where the ability of low income customers to pay is also a concern, non-linear pricing can be combined with lifeline rates as a form of cross-subsidy between customers; and

- governments, especially at the municipal level, provide *transit pricing options*, such as a subsidized annual transit pass, that motivate commuters to rely on public transit for commuting and many other mobility needs.

In order to ensure that these policies are meeting the desired goals, governments must set targets for reducing energy intensity, assess the amount of energy saved through each policy, and monitor the progress toward meeting these targets.

22.2.9.2 Accelerating the Growth of Renewables

Although depletion of low-cost fossil fuel resources may lead to rising average prices for oil, natural gas, and perhaps even coal over the next decades, one cannot assume that energy markets will, as a consequence, rapidly shift the global energy system to renewables from its current 80—85% fossil fuel dependence. First, as long as a relatively plentiful resource like coal can still use the atmosphere as a free waste receptacle for GHG emissions, this resource will remain highly competitive with renewables for the production of electricity and even vehicle fuels. Second, incumbent technologies, such as those using fossil fuels, benefit from path dependence, in which society's technological, social, and institutional capacity is geared toward the continued success of that technological path. Third, in the same vein, renewables face many barriers to massive scale-up, some of which relate to overcoming the path dependence in favor of fossil fuels, others of which relate to the specific characteristics of renewables – namely, that frequent low-energy density implies significant claims on the land base and that their intermittency requires additional, costly investments for energy storage.

For these reasons, policies to induce a rapid scale-up of renewable energy must: (1) ensure that renewables are economically attractive for investors; and (2) ensure that non-cost barriers to renewables are reduced. Policies to price GHG emissions such as taxes and cap-and-tradable permits increase the financial attractiveness of renewable energy. These policies are constrained, however, in that it is politically difficult in developed countries, and even more so in developing countries, to burden energy users with rapid energy price increases in a relatively short timeframe. This explains why jurisdictions have also provided targeted subsidies (feed-in tariffs) and market share regulations (renewable portfolio standards) to support renewables, in addition to GHG pricing initiatives. As for the non-price barriers to renewables, policymakers are increasingly realizing that these are also very important and have started to focus policy efforts on issues like regional land-use, including planning for siting hydropower, wind, and solar facilities; urban land-use, including solar access laws, siting of buildings, and building codes for solar hot water and passive solar heating and cooling; utility regulation, for transmission expansion and connection rights; and even technical training and education. Below are some key policies.

- *GHG emissions pricing* via carbon taxes and/or cap-and-trade schemes provide the clearest means of fostering renewables since these will raise the relative cost of GHG emitting forms of energy. Revenues from emissions pricing can be recycled to firms and households as income tax cuts or additional government program expenditures, but they could also be used to support emerging renewables technologies.

- *Feed-in tariffs* for renewables guarantee prospective independent power producers that all power they generate will be purchased by the grid at a fixed price. If the price is adequate, this provides a powerful inducement to equity and debt financing and explains why jurisdictions with feed-in tariffs have mostly had success in rapidly expanding renewables-based electricity generation. Feed-in tariffs may also be tailored to different renewable technologies according to their costs.

- *Market share mandates* provide a guaranteed market share for renewable energy, but they do not guarantee a price. They operate by creating confidence for investors in a steady and growing market for renewable energy. In the case of electricity, such mandates are commonly known as Renewable Portfolio Standards (RPS). Most market share standards offer the same credits to all eligible technologies, which tends to benefit the most commercially competitive technology, such as wind or corn-based ethanol, while providing no support to emerging technologies. In part for this reason, many renewables advocates argue that the feed-in tariff is a more effective policy. However, it is possible to create "tranches" for minimum shares for different forms of renewables or different types of technologies – such as a minimum market share for solar PV electric and a minimum market share for solar thermal electric.

- *Biofuel mandates* set a minimum content for fuels from biomass in gasoline, diesel, and perhaps eventually other fuels like heating oil and jet fuel.

- *Performance standards*, or intensity standards, set a maximum emissions content per unit of energy. These standards can also be tradable, leading to an average emissions content. An example in the renewable fuels context is low carbon fuel standards. While market share mandates may be effective in expanding renewables, they do not distinguish among the carbon, or other performance, of alternative fuels, be they renewable or non-renewable; if the ultimate goal is reducing emissions or emissions intensity, tradable performance standards are more effective. However, it may be noted that measuring the carbon performance of renewable fuels remains controversial.

- *Regional land-use and water-use planning* is important for scale-up of some renewables because of the potential land-use conflicts that renewables introduce. This might include river basin planning with hydropower, coastal zone planning with wind farms, land-use planning for concentrated solar power and biomass energy, and water-use planning for biomass energy. It is important that society understand that all energy options involve impacts and risks and to this end local communities must have meaningful participation in both regional planning and energy planning.

- *Electric transmission regulation and infrastructure planning* must focus on maximizing the opportunities for renewables. This includes transmission expansion that is tailored to the location of renewable resources and grid connection rules that address the particular needs of renewables.

- *Urban land-use zoning and infrastructure planning* are critical in removing barriers to decentralized renewables, via solar access rights, wind turbine siting rights, grid connection rights, and other key laws and policies.

- *Zero- and low-emission vehicle standards* can mandate a rising market share for vehicles fuelled by alternatives to end-use combustion of gasoline and diesel, such as biofuels, hydrogen, and electricity, all produced with zero- or low-life cycle GHG emissions.

- *Zero- and low-emission building standards* can mandate a rising market share for buildings that rely exclusively or almost exclusively on passive and active renewables and waste heat for heating, cooling, and ventilation.

- *Electric distribution utilities* must facilitate decentralized renewables electricity production via net metering, smart grids, and other policies.

- *Information programs, education, and other forms of capacity development* have a role to play in accelerating the growth of renewable sources of energy.

Similar to policies designed to reduce energy intensity, governments must set targets for the growth of renewable energy, assess the amount of energy supplied through each policy, and monitor the progress toward meeting these targets.

22.2.9.3 Transitioning to Cleaner Uses of Fossil Fuels

The global energy system is dominated almost everywhere by fossil fuels, but the global endowment of fossil fuels is uneven. Some countries have negligible fossil fuel resources and are thus prime candidates for a transition to renewables and – possibly – nuclear, and some, like Sweden, France, and Brazil, are already moving down this path. However, countries with rich fossil fuel endowments are less willing to consider abandoning this high energy-density resource and are thus increasingly interested in technological developments that may enable continued use of fossil fuels, albeit with low or zero emissions of pollutants and especially GHGs.

This latter step requires converting fossil fuels into electricity, heat, and perhaps hydrogen while capturing and permanently storing the carbon, mostly in the form of CO_2, probably in geological formations deep in the earth. Carbon capture and storage (CCS) is expensive and will not occur without policies that price GHG emissions. Again, because of political constraints on GHG pricing, the zero- or low-emission use of fossil fuels will require additional support. Some of the following leading policies have already been enacted on an experimental basis, but these efforts would need to be intensified significantly over the next decades to realize a dramatic shift to low- and zero-emission uses of fossil fuels.

- Governments, as noted above, can implement *GHG emissions pricing* via carbon taxes and/or cap-and-trade systems. These will reduce the use of fossil fuels but also foster commercialization efforts with CCS in some jurisdictions, enabling societies to assess with less uncertainty the viability and acceptability of this option.

- Governments can *reduce all subsidies to conventional combustion of fossil fuels, which will improve the relative competitiveness of renewables and nuclear alternatives*. This includes fuel price subsidies, subsidies to private vehicle use for urban and inter-urban travel (untolled roads), especially if fuelled by gasoline and diesel from fossil fuels, and a host of subsidies to industrial, commercial, institutional, and other combustion uses of fossil fuels.

- Governments can provide demonstration and commercialization subsidies, allocated via competitive bidding perhaps, for the initial, high-risk investments in CCS.

- Some cap-and-trade systems for emissions pricing allow firms to pay into a *technology fund* for those emissions that exceed permits. These funds can be used alone, or in concert with other government subsidies, to support early CCS projects.

- Governments can offer to *pay above-market rates* for electricity, heat, or hydrogen from projects that produce these from fossil fuels with CCS. This would be similar to the feed-in tariff for renewables.

- Governments or utility regulators could *ban construction of new coal-fired electricity plants* that lack CCS or that are not "CCS ready." Some jurisdictions in developed countries have explicitly adopted this policy. Some utility regulators in the United States and elsewhere have implicitly adopted the policy by disallowing coal-fired plants under the basis that they pose financial risks for ratepayers from future increases in GHG emissions prices.

- *Emissions performance standards* can give electricity generators the option to reduce emissions per unit of electricity either by a growing share of renewables and/or nuclear or by a growing reliance on CCS.

- *Life cycle carbon fuel mandates* can give fuel retailers the option of reducing the net GHG emissions from fuel use by increasing the content of biofuels or perhaps by including some hydrogen that is produced from fossil fuels with CCS.

- *Land-use planning* can facilitate socially and environmentally acceptable siting of underground carbon storage and CO_2 pipelines. There is also a need for land-use planning to safeguard against potential impacts of carbon storage on other uses for the subterranean, such as geothermal energy, or at least consider a balance between the possible uses.

- Governments need to *legally clarify geological rights* to underground pore spaces for CO_2 storage.

- Governments need to *establish short- and long-term liabilities and risk management and monitoring responsibilities* at CO_2 storage sites and on CO_2 pipeline right-of-ways.

22.2.9.4 Fostering the Safer Use of Nuclear Power

Views on the value and risks of nuclear power differ greatly and are often polarized. Some see nuclear power as a risky technology whose potential harm far exceeds any possible benefits it might provide, such as low GHG emissions. These perceived threats from nuclear power include catastrophic accidents at nuclear plants, either through operational failures or terrorist attacks, inability to safely transport and permanently store radioactive wastes, and the exploitation of civilian nuclear expertise for the proliferation of nuclear weapons.

Depending on the severity of these concerns about nuclear power, its regulatory burden for design, permitting, operation, and decommissioning can be such that nuclear power is a high-cost option for electricity generation. However, where local, national, and/or international public policy is able to allay these concerns, then nuclear power can be a competitive energy option. But everything hinges on risk preferences among the public and decision-makers, particularly with respect to trading off the extreme event risks of nuclear power with the ongoing impacts and risks of its alternatives. The following policies, therefore, focus on how to ensure safe use of nuclear power that is both real and perceived.

- At the international level, governments and the nuclear industry need to continue to improve the *mechanisms for monitoring and controlling the use of nuclear power* and the reprocessing of nuclear fuel to prevent the acquisition of expertise and materials for nuclear weapons production.

- Governments need to collaborate in the *establishment of permanent storage sites* for radioactive materials.

- *By facilitating collaborative investments*, governments can help the nuclear industry settle on two or three dominant designs that have the best chance of achieving regulatory approval and should thus reduce regulatory costs, which have been very high in jurisdictions like the United States.

22.3 Part II: Policy Portfolios for Sustainable Energy

22.3.1 Implementing Policies for Sustainable Energy

So far, this chapter has presented a summary of policies required to achieve the sustainable energy pathways of GEA. While these pathways are described in detail in Chapter 17, policies for sustainable energy are spread throughout GEA. This section provides further guidance on policies that are essential in some form, depending on the jurisdiction and its particular goals and challenges.

Throughout GEA, the issue has been raised that there is an urgent need to identify and promulgate key criteria that can be used to select the type and intensity of sustainable energy policies that are required to make rapid progress toward universal access to energy and a rapid transition to a cleaner, less risky global energy system.

There are two important characteristics to note about energy-related policymaking. First is the importance of understanding policymaking as an organic, iterative process. Policymaking must be a continuous learning exercise since one can never predict precisely how a policy will work. Thus, policymakers need to think experimentally when designing and implementing policies. This might mean, for example, deliberately creating real-world variations by implementing different policies or policy variants in different locations within a given jurisdiction in order to generate more useful data on policy effectiveness. To this end, the steps of policy monitoring, policy evaluation, and policy redesign are essential to good policymaking.

The second is the critical role of institutions and governance. Without effective institutions and governance practices, policies have little chance of success. Assessments of policy design and policy effectiveness cannot be divorced from efforts to improve governance. This includes: (1) increasing transparency and public involvement to reduce the risks of corruption; (2) developing higher standards for education; (3) monitoring and evaluation of the civil service; (4) ensuring effective, independent controls by the legal system; and (5) strengthening the policymaking functions of democratic processes in various ways.

This section outlines policies that can achieve the eight goals for sustainable energy policy discussed earlier in this chapter. Again, these are:

1. increase energy access;
2. develop capacities for energy transitions;
3. enhance energy security;
4. manage energy-related market power;
5. manage valuable energy resource endowments;
6. reduce environmental and human health impacts;
7. accelerate the rate of energy-related technological change; and
8. coordinate and implement international energy-related policies.

Each of the goals demands its own unique policies, but policies must be implemented in a coordinated, integrated, and mutually consistent fashion. Chapter 17 presented pathways for achieving these goals in terms of the contributions from different actions, such as increased energy efficiency, switching to more desirable fuels and technologies, better prevention and control of pollutants, and stimulating major investments to increase energy access and improve energy security. The pathways include: (1) one that strongly emphasizes energy efficiency; (2) one that focuses on a cleaner, more sustainable energy supply mix; and (3) one that is a mix of these two contrasting strategies.

The policies presented here have been selected to ensure achievement of the GEA pathways. A dominant focus is the substantial, coordinated effort required for making major economy-wide advances in energy efficiency. This includes focused, somewhat aggressive policies. Such policies are needed to induce rapid innovation, tighten efficiency regulations in energy supply and demand, and increase energy prices. The policies must create a culture of conservation among consumers and firms, change land-use zoning to increase urban density, and integrate mixed land-uses so that transportation service demands decline while low energy-using transportation modes flourish.

Achievement of greater energy efficiency, alongside a rapid increase in the use of renewable energy, cannot be pursued in isolation. These goals must be intrinsically linked to broader social and economic development goals on the one hand and to environmental protection and restoration goals on the other. Providing adequate access to modern forms of energy is a critical contributor to social and economic development that can substantially improve the standard of living of the most disadvantaged people on earth. At the same time, a rapid transition to an energy system with negligible greenhouse gas emissions is critical for preventing destabilization of the earth's climate system.

At the policy level, a similar relationship exists. Energy-focused policies must not be conceived and implemented in an isolated fashion, but instead coordinated and integrated with non-energy policies for socio-economic development and environmental protection. These latter include policies that foster sustainable urban areas, preserve forested land and biodiversity, reduce poverty, provide environmentally acceptable transportation of goods and people, ensure vibrant communities, and improve human health.

An emphasis on policy integration is a common theme throughout GEA. This explains why the Millennium Development Goals are a key consideration in the design of policies for energy access, capacity development, clean energy for households, and emissions reduction at the urban and regional levels. It also explains why broader development goals that push for accelerating the rate of energy technology innovation are a key consideration in the design of policies.

While virtually every chapter in GEA provides specific policy suggestions, this chapter and the following three (Chapters 23–25) focus especially on issues related to policy design and implementation. The section that follows combines policies from these chapters with policies found throughout GEA to produce a portfolio of policies associated with the sustainable energy pathways of Chapter 17.

To this end, the following is divided into three sections. This section, Section 22.3.1, provides a portfolio of key energy policies to address the eight major energy policy goals identified in GEA. Section 22.3.2 provides a set of policies focused especially on energy efficiency. They explain how additional policies could intensify energy efficiency efforts in order to meet the aggressive targets of the most ambitious efficiency-focused pathways. Section 22.3.3 summarizes the links between policy objectives, policy types, and investments required for the rapid transformation of the global energy system. This transformation necessitates a rapid increase in energy access in the developing world, improvements in energy security in all energy systems, and, finally, the adoption of energy technologies with much lower environmental and human impacts.

This section does not recapitulate the long list of policies contained throughout GEA, which is a very large list with, at times, specific recommendations for specific situations from social, cultural, technological, and geographic considerations. Instead, what is provided is a summary of the salient policies associated with each of the key goals, in general, and a rather precise set of policies necessary to achieve the ambitious energy efficiency improvements described in Chapter 17, in particular. Thus, these policies are not distinguished by level of economic development, type of political system, institutional arrangements, or other critical factors in real-world policy design, implementation, and review.

For case studies, literature references, and arguments to defend specific policy designs, readers can refer to the policy chapters (Chapters 22–25), as well as to specific policy discussions in individual chapters throughout GEA, depending on their specific area of interest.

22.3.1.1 Increase Energy Access

As explained in Chapter 23, because increasing access to modern forms of clean, affordable, and efficient energy is an issue of equal importance to both developed and developing countries, in urban slums as well as rural hinterlands, there is no single set of policies that can increase energy access. The following portfolio of policies was put together with developing countries particularly in mind, where access to energy tends to be lower than in developed countries. While these policies are energy-focused, their effectiveness depends on coordination with broader policies in pursuit of social and economic development – investments in education, human health, poverty reduction, social and cultural support, sound institutions, and effective government.

- Competitive bidding to allocate funds to private, public, or cooperative grid owners or managers to extend high voltage transmission lines to unserved regions or communities and to extend low voltage distribution lines to unserved households via low hook-up fees. Funding could come from government or utilities.

- Competitive bidding to allocate funds to private, public, or cooperative enterprises to provide electricity services in isolated communities or regions that are too remote for connection to the grid. This may involve subsidized installation of household devices, like solar arrays, or larger community-based systems that may use any type of renewable energy or perhaps low-carbon fossil fuels and may cogenerate electricity with heating and/or cooling services.

- Lifeline rates that ensure a basic low price for an initial quantity of electricity, with higher rates for additional amounts.

- Electric utility tariffs that provide cross subsidies from one rate class of electricity customers to another to ensure electricity access for the poorest customers. Utility funds could be augmented by public sources of revenue.

- Public funding (grants, micro-financing) for the acquisition of stoves, heaters, and other devices that use clean-burning gaseous and liquid fuels or that can combust solid fuels (coal, charcoal, biomass) without deleterious emissions that adversely affect indoor air quality or the air quality in sensitive urban and rural airsheds.

22.3.1.2 Develop Capacities for Energy Transitions

Energy capacity development does not achieve energy transitions via a few simple policies (see Chapter 25). It requires a holistic approach that recognizes the complex interconnection of capabilities, habits, and norms of actors at all levels of the energy system. This is why Chapter 25 introduces the capacity matrix as a tool for conceptualizing how capacity development from a broad systemic perspective can play a critical role in energy transitions. It is also why there is considerable regional disaggregation in Chapter 25 – to reflect differences in cultural norms, technical skills, and access to information, not just between developed and developing countries, but also depending on the specific attributes of a given continent, region, country, and even sub-national locales.

- An energy capacity strategy must be tailored to the specific characteristics of a given location if it is to succeed in provoking a rapid transition of the energy system toward a more sustainable path. While this strategy would address basic needs for education and training, it should also be adapted to the cultural norms and practices of that location.

- Developed countries need to improve mechanisms for supporting capacity development in developing countries, including financial support, technical training, sharing of industry, trade, institutional experiences, and public education.

22.3.1.3 Enhance Energy Security

Policies by different levels of government and different institutions all have a role to play in helping reduce or respond to energy security concerns. Energy security concerns are categorized in Chapter 5 as structural, sovereignty, and resilience. Policies to address systemic risk emphasize improved management of energy system design and operation. Policies to address risks from foreign sources emphasize avoiding or mitigating external control of energy supply or hostile actions that might disrupt supply from external sources. Finally, resilience or robustness of an energy system is a critical attribute for improving energy security prospects.

While energy security is often presented as a focus of industrialized countries, where a high level of reliability is essential for modern communications and production systems, it is also of great importance for developing countries. Micro-enterprises that lack back-up self-generation are particularly vulnerable to blackouts that are a daily occurrence in many parts of the developing world. The recommendations below are designed to address these various energy security risks.

- Electric utilities should make timely supply additions and provide regular system maintenance to ensure adequate reserve capacity and back-up generation to reduce the chance of unprovoked system failure.

- Regional cooperation can play a vital role in ensuring energy security in a sustainable manner. Energy trading can help meet energy demand while maximizing scarce natural resources in the sub-region. By utilizing different peak times of neighboring countries, regional power trade can reduce the need to build new power plants in each country. Transmission interconnections that enhance reliability by allowing for exchanges between contiguous grids should be developed up to the point where their marginal potential benefits in terms of risk reduction equal their marginal costs of provision.

- Electric system operators should provide tariffs and foster technologies that reward generators and consumers who can modulate their electricity flows in to and out of the grid in immediate response to signals from the operator.

- Diversity of primary energy supply should be pursued when the costs of additional diversity are likely to be below the expected benefits depending on an assessment of contingent reliability risks. This desired diversity may be by energy form (reduced reliance on oil or some other form of energy) or by supplier (reduced reliance on supplies from one region or country).

- National governments could develop alone, or in concert with other governments, mechanisms to stockpile energy resources that have significant risks of supply disruption or price volatility so that they can release these into the market (domestic or international) at times of scarcity, thereby reducing price volatility and supply insecurity.

- During periods of unusually high energy prices, governments may decide to protect the most vulnerable users from extreme energy price increases, but they should be careful not to completely constrain prices for energy suppliers and users as this would mute market responses (increased supply, decreased demand) that are normally triggered by high prices and that eventually lead to a new equilibrium of secure supply at prices that may be acceptable even if somewhat higher than before.

- When it can be shown to increase energy security at a reasonable cost, governments could push for an increased share of local energy supply through incentives such as tax advantages, regulatory flexibility for municipalities to encourage distributed and decentralized energy supply, and grants and loans for feasibility studies and capital costs related to district energy systems, as well as support for knowledge and technical capacity building.

22.3.1.4 Manage Energy-related Market Power

Significant economies-of-scale in some parts of the energy system – transmission and distribution of electricity and natural gas, oil pipelines, district heat networks – mean that market power can be socially desirable from an economic efficiency perspective. In such natural monopoly cases, the policy challenge is to regulate public or private monopolies so that their market power does not distort upstream or downstream phases of the industry where competition may be effective, such as oil and gas production, electricity generation, retail energy commodity markets, and energy service markets. In other parts of the energy system, economies-of-scale do not create natural monopoly conditions, but they make it likely that the industry will be dominated by a few large firms. The petroleum industry is especially known for oligopoly forms of market power, which may call for various policies to protect the public interest.

- Whether transmission and distribution monopolies are publicly or privately owned, oversight by an independent monopoly regulator is likely to be in society's interest. The regulator should have expertise in economics, engineering, accounting, and environment and the authority to review for prudent utility decisions about investments, rate levels, rate design, and associated environmental and social trade-offs.

- Government and/or the monopoly regulator should ensure that monopoly power in one phase of an industry does not confer power over other levels of the industry, especially if competition is desired for these levels. This requires a separation of grid operation and regulation from electricity generation activities, even if this separation is more functional than corporate and even if some aspects of electricity generation are still treated as a natural monopoly.

- Government and/or the monopoly regulator could require the monopoly to play a role in delivering energy efficiency programs and increasing public awareness of economic, environmental, and social considerations in business and household choices of technology and lifestyle that affect energy use. Alternatively, another entity could be given responsibility for energy efficiency.

- If governments pursue competition in electricity generation they need to understand the special nature of electricity, in particular the need to balance all demand and supply on the grid instantaneously. An authority should be created to administer the competitive market, regulate electricity supply and demand, and prevent the short-term exercise of market power in ways that cause dramatic price spikes to the detriment of some customers.

- Government and/or the monopoly regulator need to make sure that the electric monopoly has the capability and authority to plan and operate the grid in an economically, socially, and environmentally sustainable manner. This capacity increases in importance with the need for dramatic transformation of electricity supply – for instance, many small-scale, decentralized generators, some of them located in urban areas, some in isolated regions that are favorable to renewable electricity generation – and electricity demand, such as smart meters that communicate between private energy-using devices and the grid operator, and electricity generation downstream of the meter in private buildings.

- In non-monopoly cases of market power, as sometimes occurs in electricity generation, oil and gas industries, anti-trust regulatory policies must be strong enough to ensure that a few large firms cannot: (1) distort markets in ways that reduce long-run energy security;

(2) allow industry to capture excess profits from consumers via price inflation; or (3) interfere in some way with effective governance. Where the firms are associated with a particularly valuable energy resource like petroleum and natural gas, policies are also required to effectively manage this public endowment (as outlined in the next Section 22.3.2) and provide a competitive environment to promote private sector investment.

- Market power sometimes equates to political power – the ability to influence public policies in favor of a particular industry or firm. Subsidies are one manifestation of this power. While subsidies are sometimes a valuable policy tool for advancing economic and social objectives, governments must be vigilant over time that subsidies not work at cross purposes to other objectives and do not become entrenched long after their justification has passed.

- The policy portfolio should seek to eliminate or substantially reduce subsidies, such as tax breaks and royalty reductions, which work at cross-purposes to overall policy goals. For example, if the intention is to reduce reliance on fossil fuels, subsidies to oil and gas exploration and development should be eliminated, as should subsidies to the coal mining industry.

22.3.1.5 Manage Valuable Energy Resource Endowments

Depending on market conditions and international prices, petroleum and natural gas can provide massive revenue streams in countries that are particularly well endowed with these premium sources of energy. While these lucrative rents could be a short- and long-run benefit to society, this is not always the case. Sometimes the resulting rent-seeking behavior contributes to corruption and poor governance – the resource curse – and the boom and bust cycle of commodity prices swings the economy from periods of excess wealth and waste to periods of severe recession. Policies are needed to manage the revenues in ways that maximize the long-run benefits from valuable resource endowments and prepare the economy for the time when these resources are depleted or lose their value. Also, the influx of foreign investment capital pushes up the value of the currency, threatening the survival of other domestic industries. Policies are needed to help these other domestic industries survive if they have the potential to provide sustainable benefits to the economy.

- Policies should control the rate of resource exploitation so that its demand for labor and capital (with resulting inflationary effects) does not irreparably undermine other sectors of the economy (e.g., renewable resources, technology, and services) that otherwise have good prospects of providing value long after the resource is depleted.

- Policies should maximize the collection of economic rents (surplus profits) from the resource for present and future generations. Rents can be captured via royalties and income taxes on private firms and/or by a significant role for state-owned energy companies. In the latter case, management incentives and transparency are necessary to ensure that these companies are efficiently operated and accountable.

- Some part of resource rents could be streamed into sovereign wealth funds that are invested domestically and abroad in an effort to maximize the stream of expected benefits to future generations. This means a balanced portfolio of riskier and safer investments. Foreign investment with these funds can also help reduce upward pressure on the value of the currency, thus helping other domestic industries stay competitive. A poorer country will want to invest more of the rents domestically in infrastructure, education, and social services for the present generation, as this is likely to offer good potential for benefiting present and future generations. But resource rents should rarely be used to subsidize domestic energy prices, as this only dissipates the rent in inefficient current energy use.

- Some of the resource rents could be used to help the economy smooth out the boom-bust cycle of commodity prices. But such efforts should be limited and cautious, since it is impossible to know whether future resource prices will be higher or lower than current levels. These rents can also be used to sustain an economy once the resource is depleted.

- Policies should ensure transparency of resource rent flows and the budgets of government ministries, state-owned operations, and foreign resource companies in order to minimize the opportunities for rent dissipation through corruption. An example is to use principles from the extractive industries transparency initiative.

- Collected resource rents can also be used to repair environmental damage and can be allocated to communities most negatively affected by resource exploitation.

22.3.1.6 Reduce Environmental and Human Health Impacts

Energy supply and use involves a wide range of risks and impacts on humans and the environment. Energy use plays a large role in poor urban air quality and poor indoor air quality from open burning of solid fuels, which negatively affects human health. Energy extraction and processing can have substantial and sometimes devastating effects on the landscape and on soil and water resources. And, increasingly, the role of the current energy system in increasing atmospheric concentrations of greenhouse gases will cause rapid destabilization of the planet's climate, weather, water resources, and ecosystems, as well as human land-use and their social and economic systems.

While some of these energy system effects are known and fairly predictable, others present risks with very high uncertainties, which complicates and hinders the development of collective actions to reduce environmental and human risks. A sustainable energy policy portfolio would, at a minimum, include the following elements.

- A mix of regulations, information programs, and subsidies are needed to stimulate the rapid adoption of household energy using devices (stoves, heaters) that have virtually zero indoor emissions. While fuel subsidies may be used in a limited fashion, it is generally preferable to provide subsidies and low-cost financing for the acquisition of equipment, such as efficient, zero-indoor-emission stoves (using gaseous, liquid, or solid fuels) and efficient electric light bulbs to replace the indoor combustion of kerosene and other fuels for lighting.

- Urban air quality must be protected or restored by regulations on emissions from fuel combustion in buildings, industry, and vehicles in urban settings. Some regulations may be highly prescriptive (specifying combustion technologies such as the use of catalytic converters, restricting certain fuels, or requiring connection to district heating and cooling systems), while others may focus on the absorptive capacity of a given urban airshed for a particular pollutant. The latter case could involve the establishment of airshed emission limits, perhaps involving a cap-and-trade system. Or, it could involve the establishment of emission taxes of some kind.

- As with urban air quality, regional air quality must be protected by technology and/or emissions regulations or by direct emissions pricing. Again, some form of cap that is directly related to absorptive capacity has the best chance of meeting environmental objectives. A cap-and-trade system can, however, be difficult to achieve, depending on the complexity of emissions sources and the administrative capacity of the institution that will administer and oversee the trading system.

- Extractive activities and land/water uses – e.g., coal mines, oil and gas fields, hydropower dams, diversions and reservoirs, nuclear plants, storage sites for radioactive wastes and captured carbon dioxide, wind farms, solar electricity farms – should be subject to a permitting and regulatory framework that assesses their benefits against a precautionary consideration of their impacts and risks. In some cases, this may result in regulation and controls placed on the activity in order to reduce impacts and risks and, in some cases, in the complete rejection of the activity.

- Policies are needed to accelerate the development of renewable forms of electricity generation. These include possibly a feed-in-tariff that provides a minimum price for electricity from renewable sources and/or a renewable portfolio standard that sets a minimum but growing market share for renewable electricity. In order to maximize the effectiveness of a feed-in-tariff, it should identify the source of funding and have a clear sunset provision that pushes project developers to lower the cost of power.

- Policies fostering energy from biomass should recognize the trade-off between biomass-for-food, biomass-for-fuel, and the conservation of biodiversity. Subsidies to corn-based ethanol have encouraged inefficient production of biofuel with greater than necessary pressures on food prices. Better policies would encourage the use of biomass residues and only the most efficient biomass feedstocks and conversion processes.

- Policies to foster the safe development of nuclear power can help reduce the reliance on fossil fuels and associated greenhouse gas emissions. But development of nuclear power requires an integration of policies for developing technological and institutional capacities for producing nuclear power in a given country. It also requires ongoing development of existing international institutions and processes for ensuring that nuclear technology is not diverted to weapons production.

The following policies focus on key, specific sources of greenhouse gas emissions, namely fossil fuel use in industry, buildings, the transportation sector, and the generation of electricity.

- GHG pricing (via cap-and-trade and/or carbon tax) provides the essential major long-run mechanism by which energy systems gradually shift toward low carbon emission technologies, fuels, and activities. However, policies are also required that drive initial development of new technologies that must pass scale-up thresholds to the point where experience and learning drive down costs and accelerate adoption. Major public subsidies may drive early development of carbon capture and storage from large point-sources of GHGs, such as coal-fired electricity plants, oil sands plants, coal-to-liquids plants, and some industrial plants. Another approach is to apply niche market regulations that require specific sectors to gradually increase the percentage of carbon they process that is captured and stored, called a carbon capture and storage performance standard. The goal of such an approach is to create incentives for the pursuit of an increasing number of profitable CCS projects.

- Governments must use targeted policies to swiftly overcome a lack of regulatory clarity and challenging financial barriers if they want to succeed in CCS deployment on a commercial-scale. Key policies include: (1) allocating public funds to a number of different industries to share in the initial, high-risk investments associated with the first commercial CCS projects; and (2) developing a regulatory environment conducive to CCS in terms of property rights and liabilities. For instance, governments or utility regulators could prohibit construction of new coal-fired electricity plants that lack CCS or that are not CCS-ready. Such a policy approach would occur initially in developed countries with a lagged application, along with funding support, and in developing countries as part of an international agreement. Furthermore, the creation of CCS-specific measurement and crediting protocols will be key to ensuring that CCS projects are as tradable or valuable under national GHG regulatory frameworks as other qualifying emission reduction options.

- Governments need to develop property rights and regulatory policies that clarify short- and long-term management responsibilities and liabilities for geological storage of carbon dioxide, just as they have established these for the storage of other undesired gaseous and liquid by-products.

- Regulatory policies (e.g., land-use zoning, building codes, development permitting, and local emission standards) are needed to drive a shift toward low- and zero-emission buildings. In some cases this can be done in concert with low- and zero-emission decentralized energy supply. New urban developments should be required – initially most stringently in developed countries – to be low- and zero-emission of local air pollutants and GHG emissions via the local production of energy from solar, wind, biomass, and other sources and through import of energy from zero-emission external sources. These requirements could be gradually phased in to drive the retrofit of existing buildings and redevelopment of existing urban areas.

- Vehicle emission standard policies can require manufacturers and retailers to achieve minimum levels of sales of low- and zero-emission vehicles. This can start at modest percentages initially to allow the establishment of a niche market that enables learning and experience to lower production costs, but it should be enabled to grow substantially over the next two decades toward market domination. Alternatively, vehicle emission standard policies can set average emission standards for new vehicles.

- Similar niche market emission standards should be applied to other modes of transport, namely buses, trucks, off-road vehicles and mobile equipment, boats, trains, and airplanes.

22.3.1.7 Accelerate the Rate of Energy-related Technological Change

Some of the previous sections include policies that would help to drive rapid technological change. These include an economy-wide GHG emissions price that changes the incentives for innovation of new technologies and for their adoption. Also promoted are certain types of regulations, such as renewable portfolio standards and other niche market regulations for low- and zero-emission vehicles, which also help motivate industry to innovate and market technologies with desirable attributes from an environmental or social perspective.

In this section, it is reiterated that policymakers should ensure that a sustainable energy policy portfolio consistently applies an innovation system perspective, which will be further emphasized in Chapter 24.

- A sustainable energy policy portfolio should combine supply-push and demand-pull policies to ensure that adequate resources are available for innovation. This means, for example, subsidies, tax credits, and patents law on the supply side. On the demand side, polices should encourage sufficient market demand to move innovations from the new technology phase to significant initial levels of early adoption, and eventually toward industrial competition. The portfolio should recognize the importance of innovation spillovers, ensuring that technological breakthroughs can be widely applied. It should also ensure that patent law does not hinder rapid innovation.

- Subsidies might be used in some cases to bridge the gap between development and commercialization. But this should be done only when such subsidies are expected to lead to lower costs for technologies that will have a good chance of success in the future energy system in which market prices have been corrected to reflect environmental and social externality costs. From the outset it should be clear that such subsidies are temporary via the use of sunset clauses or other termination provisions.

- A policy portfolio must try to find an appropriate balance between picking winners and letting the market decide. The vehicle emission standard provides an example in that it picks a winner by requiring that vehicles be low-emission or zero-emission, but gives flexibility to innovators and market adopters by not specifying whether such vehicles are driven by electricity, biofuels, or hydrogen. Likewise, the renewable portfolio standard picks a winner by forcing the market growth of renewable electricity, but it lets innovators and the market decide by not specifying which renewables should dominate.

22.3.1.8 Coordinate and Implement International Energy-related Policies

Globalization of the world's economic system goes hand in hand with globalization of its energy system. Prices for energy commodities are increasingly set internationally, starting initially with crude oil but now extending to natural gas, coal, refined petroleum products, and bio-fuels. Even electricity prices are increasingly influenced at the international level within European and North American markets. Political disputes between countries (Israel and Arab OPEC countries; Russia and Ukraine) can threaten energy security and energy prices in far-distant consuming countries. At the same time, the environmental impacts of energy use have become global, especially with the key role of fossil fuel combustion in rising GHG emissions. Finally, international energy policies, as well as international aid, should bear in mind the urgent need for energy access and clean energy in developing countries.

- A sustainable energy policy portfolio must include effective mechanisms by which developed countries can assure a rapid transfer of financial, technological, and institutional resources to developing countries for energy system development and transformation. Key international and multi-national institutions, such as the World Bank, the International Monetary Fund, divisions of the United Nations, and development banks such as the Asian Development Bank, African Development Bank, and Inter-American Development Bank, must ensure that their policies contribute in a consistent and effective way to all of the key energy policy goals of GEA (access, security, managing market power, environment, etc.).

- A sustainable energy policy portfolio must also include mechanisms by which countries can coordinate efforts to reduce energy price volatility (although it cannot be eliminated). These include diversifying suppliers, stockpiling energy, establishing back-up electricity and fuel supply systems, developing inter-regional electricity and natural gas trade, and discouraging the use of energy as a political weapon.

- At the international level, governments and the nuclear industry need to continue to improve their mechanisms for monitoring and controlling the use of nuclear power and the reprocessing of nuclear fuel to prevent acquisition of expertise and materials for nuclear weapons production. For instance, proliferation resistance could be increased through policies aimed at phasing out reprocessing as rapidly as possible, and placing enrichment plants under multinational management and restricting them to stable regions. Governments need to collaborate in the establishment of regional storage sites for radioactive materials. Design of the repositories should be subject to international standards and oversight to ensure that the import of spent fuel from richer countries to poorer countries would not create undue environmental hazards (see Chapter 14).

- A sustainable energy policy portfolio must include one or more mechanisms to ensure that global concentrations of GHGs in the atmosphere do not reach levels that are highly risky for human and environmental health. These mechanisms could be, for instance, country-specific targets for GHG emissions established through international negotiations based on almost universal agreement. Or, the mechanisms may be targets and obligations negotiated by individual sectors, such as specific requirements for coal-fired electricity plants to gradually incorporate CCS, or for the airline industry to gradually increase the bio-fuel share of jet fuel, or for the vehicle industry to have a rising share of zero-emission vehicles worldwide. As indicated, international coordination is necessary to mitigate emission leakage and other issues that may arise from only a subset of countries being covered by these policies.

22.3.2 Policy Portfolio Focused on Energy Efficiency

Chapter 17 presents scenarios that are distinguished in part by the degree to which energy efficiency contributes to a sustainable energy system. In part three of this chapter, the focus is on presenting the type and intensity of policy effort required to realize a global sustainable energy pathway through dramatically lower levels of energy use.

Since this is not a precise policy modeling exercise, the policies here are not calibrated to the intensity levels that would exactly match the scenarios in Chapter 17. What is presented here, instead, are descriptions of policies that can accelerate energy efficiency trends, along with suggestions on the intensity with which such policies would need to be applied in order to achieve the most ambitious energy efficiency scenario.

It is important to note, however, that achieving an aggressive energy efficiency scenario is not just a question of turning up the intensity on policy levers. If societies are to achieve development paths in which efficient technologies are rapidly innovated and adopted, while at the same time there is widespread acceptance of a conserver lifestyle, there must be social acceptance of energy policies that drive not only technological change, but also changes in some key behavioral expectations. One major example is the ownership and rate of use of private vehicles. Such a level of change is more likely to succeed if it is fostered by the development of an enabling environment. This requires the creation of a broadly shared vision that would permeate a given society's institutions, infrastructure, education, technical capacities, financial and market conditions, laws, regulations, and social norms.

The rebound effect is a critical consideration when assessing the potential for energy efficiency policies to dramatically reduce energy use. Efficiency regulations on their own are likely to increase the rebound effect – because of lower operating costs and efficiency innovations that stimulate new energy devices and services – unless they are compensated by policies that increase energy prices to reflect environmental and social externalities and that shift energy rate structures (in the case of tariffs set by electric, natural gas, and district heating utilities) to reflect the full long-run cost of new supplies. These kinds of policy changes will be challenging to enact. In the description below of ambitious energy efficiency policies, the emphasis is on those that offer the best prospects of delivering this major transformation in the relatively short period of a few decades.

There are a number of ways of presenting energy efficiency policies – by level of government, by type of policy, by source of energy, by intensity of the efficiency effort, or by end-use sector. In this section, energy efficiency policies are organized by end-use sector. They also include upstream policies affecting individual energy supply systems for electricity, fuels, and heat. Thus, this portfolio of energy efficiency policies has the following sections: industry; appliances and devices (office equipment, personal products); buildings; urban form; transportation; and agriculture.

As with the previous section, the policies in this section represent only a subset of the possible policies in a sustainable energy policy portfolio. A more detailed description of policies, with many case studies of successes and failures, is provided by the other policy chapters and indeed in most other chapters of GEA. Any particular government should collect key information on the use of energy in industry, transport, commercial, and residential sectors if it is to develop effective policies for its own energy efficiency pathway.

In all policy cases discussed below, it is assumed that energy forms with GHG emissions associated with them, at the point of use or during production – as in the case of electricity generation – will experience rising prices over the coming decades due to economy-wide GHG emissions pricing policies, i.e., tax or cap-and-trade. In the same vein, regional and local air and water pollutants are assumed to face rising costs through externality pricing policies and regulations that affect the cost of emissions and effluents.

Most analysts argue that pricing policies are the most efficient and effective way to drive much of the investment and behavioral change needed for a major transformation of the energy system. Others argue, however, that pricing policies alone are insufficient to achieve the desired policy objectives. They contend that complementary regulations, subsidies, public investments and other policies are needed to realize a rapid and profound transformation of technologies, fuels, buildings, urban form, infrastructure, and industrial plants.

Thus, depending on one's perspective, the policies listed below can be seen as potential complements to pricing policies, intended to accelerate efficiency actions that would be stimulated by rising prices. Complementary policies must be designed and implemented carefully, however, to reduce the risk that they will have a negligible effect or even negative unintended consequences.

22.3.2.1 Energy Efficiency Policies for Industry[5]

Development of GHG emissions pricing and other policies that internalize the costs of environmental harm and impact on humans will provide additional incentive for industry to adopt more efficient energy-using technologies. Additional policies may accelerate the adoption of high efficiency technologies, but they must be applied carefully. In some cases, their incremental effect will be zero once prices have been corrected to reflect environmental harm. In some cases, they may actually work at cross purposes with price-adjusting policies.

- Governments and utilities can design utility tariffs to ensure that the marginal tariffs facing customers reflect the true marginal costs of providing them with energy. Depending on the characteristics of the energy supply system, this involves time-of-use rates and/or inverted block rates in which marginal tariffs reflect an appropriate weighting of short- and long-run marginal costs.

- Governments can set regulations that are updated (for example, every five years) to prohibit market access to the least efficient third or half of technologies for a given service, such as motors, fans, conveyors, blowers, boilers, cogenerators, and process-specific equipment.

- Governments can implement "golden carrot" policies and/or niche market regulations that use financial incentives or regulation, or a combination of both, to encourage industry to develop and adopt technologies that are more efficient than the current stock.

- Governments can establish efficiency performance standards for major industries. Or governments can mandate processes that require new investments to achieve a best available technology efficiency standard. Also, phased retrofit of already installed process technologies can be required.

- Governments can provide free audits for smaller firms that find it too costly to inform themselves of energy efficiency options and audits for a fee for medium and larger firms.

- Governments can require firms of a certain size to have full-time energy managers responsible for identifying efficiency opportunities.

- Governments and utilities can provide up-front funds or financing arrangements to ensure that capital constraints are not a barrier to energy efficiency investments.

- Local governments can plan and regulate the location of industrial activities in order to maximize opportunities for waste heat transfer and other synergies between industries to reduce material and energy use.

- National and international industry associations can ensure that industries throughout the world are informed of the most energy efficient processes and technologies.

- Some modifications to patent laws may help improve innovation and a relatively quick transfer of energy efficient technology for industries in different countries.

22.3.2.2 Energy Efficiency Policies for Appliances and Devices[6]

While energy intensive industries are normally very sensitive to energy price – and therefore its technology choices will be affected to a considerable extent by emissions pricing policies – the same is not always true to the same degree with commercial and residential energy users. One reason is the difficulty and cost in getting adequate information about the efficiency of alternative equipment relative to the potential savings for a small-scale energy user. Another reason is the challenge for small consumers in demonstrating to financial institutions the lower operating cost benefits resulting from up-front investments in energy efficiency. In contrast, large industries are continually engaged in explaining the benefits and costs of their investments to financial organizations. A third

5 See also Chapter 8.

6 See also Chapter 10.

reason is the split incentive that often exists between the landlord, who pays for appliances and some devices, and the commercial or residential customer, who pays the energy bills. The following policies seek to address these challenges.

- Governments and utilities can ensure that marginal tariffs facing customers reflect the marginal costs of providing them with energy. Depending on the characteristics of the energy supply system, this involves time-of-use rates and/or inverted block rates in which marginal tariffs reflect an appropriate weighting of short- and long-run marginal costs. With the falling cost of meters, such tariffs are now possible for even the smallest customers.

- Governments can set regulations that are updated every five years to prohibit market access to the least efficient third or half of appliances and devices. Alternatively, these regulations can ban or mandate the phase out of certain types of less efficient technologies, such as incandescent lights.

- Governments can set regulations that prohibit appliances and devices that use electricity while not in use (turned-off, sleeping, or in standby mode).

- Governments can require efficiency rating labels on appliances and devices to raise public awareness about operating costs of such devices relative to average efficiency.

- Governments and industry associations can work to reach internationally sanctioned appliance and device standards to prevent inefficient products being phased out in industrialized countries from being transferred to developing countries, with the consequence of locking such countries into a regime of inefficient energy use and high operating costs.

- Governments can implement golden carrot policies and/or niche market regulations that use regulation or financial incentives (or a combination of both) to require manufacturers to develop and market appliances and devices that push the envelope to yet higher levels of efficiency than have thus far been experienced. This can perhaps be done initially with a subset of consumers.

- Governments and utilities can provide subsidies for early adopters of high efficiency appliances and devices, although such programs should only reward the adoption of technologies that are unlikely to have otherwise been adopted, because free-riders are a well known challenge to subsidy policy effectiveness.

- Governments and utility regulators can ensure that utilities and energy service companies have an incentive to play a key role in promoting energy efficiency among customers of all classes, particularly small-scale customers who lack resources and knowledge to access energy efficiency. This involves initiatives such as: (1) decoupling utility profits from sales; and (2) creating tradable "white certificates" by which utilities can trade energy efficiency credits among themselves as they compete to achieve energy efficiency targets set by regulators.

22.3.2.3 Energy Efficiency Policies for Buildings[7]

Buildings use approximately one-third of all the energy used globally and are responsible for about one-third of the total energy-related emissions of GHGs (including emissions from electricity production). Because the building stock turns over slowly and because energy efficiency is much less costly if it is built in at the time of design and construction, policies usually distinguish between those affecting new buildings and those affecting existing buildings.

- For new buildings, governments can establish a set schedule for tightening over time the energy efficiency standards for the building shell; heating, ventilation, and air conditioning (HVAC) system; and domestic water heating systems to reach very low levels of energy use. The phase-in period for the strictest efficiency standards could be shorter in developed countries (a decade) than in developing countries (two or three decades in urban areas), although country-, region- and city-specific criteria could lead to very different timeframes. The phase-in period for the efficiency requirements and their stringency would be tightest for the highest efficiency scenario.

- For new buildings, governments can use development charges and siting requirements to ensure that buildings are sized and located appropriately for optimizing heat gains and losses of the building shell, depending on climate and the building's heating or cooling needs, with respect to its ambient surroundings. These can also be applied, in many cases, to maximize opportunities for waste heat recovery and/or district heating supply.

- Governments can require all existing buildings to have an energy audit at the time of sale that shows prospective buyers how the building ranks on a scale showing energy efficiency performance and GHG emissions. This would include estimated future energy costs associated with rising emissions charges. Audit results should be clearly highlighted in information related to advertising and execution of sale.

- Governments can provide subsidies (tax credits, grants, low-interest loans) for retrofits in existing buildings that drive emissions to zero and/or external energy inputs to zero for a given building. In developed countries, funds can be acquired through local improvement charges and assigned to a property rather than a person. For developing countries, funds could be acquired from domestic sources and perhaps through international transfer mechanisms like the Clean Development Mechanism (CDM). For scenarios of high-energy efficiency, retrofit subsidy programs should be much more substantial.

7 See also Chaper 10.

22.3.2.4 Energy Efficiency Policies for Urban Form

The energy efficiency of the built environment can be improved substantially through urban planning that combines land-use planning, transportation management, and a synergistic approach to the provision of energy and water services (see also Chapter 18). Such a "community energy management" approach is characterized by increased urban density and especially associated with infrastructure for public transit and district heating, mixed land-uses that reduce the need for mobility and increase the attractiveness of walking and cycling, and coordinated developments that maximize the potential between and within buildings for energy cascading – the use of waste heat. This approach can reduce use and increase reuse of water and sometimes other materials, thus indirectly reducing energy use for these services. Attractive, high-density living also increases energy efficiency by reducing the ratio of external walls to floor space in residential dwellings. Community energy management policies include the following.

- Local governments can set land-use zoning and development standards to foster targeted densities and mixed uses to reduce travel and transportation needs, energy efficient buildings, and cogeneration.
- Local governments can negotiate explicit energy performance standards into permits for re-zoning and new buildings.
- Local and regional governments can foster strategic alliances between energy utilities and developers, with explicit energy planning requirements in official community plans.
- National and regional governments can legislate the requirement that energy planning be an explicit function of local and perhaps regional governments.
- Governments can provide technical and financial support for the integration of energy considerations into traditional community planning processes.
- Governments can tie infrastructure grants to the implementation of community energy management strategies.
- Governments can reduce or eliminate minimum parking stall requirements for new developments and increase local taxes on parking spaces.
- Along with reducing incentives for vehicle traffic, governments can increase the provision of public and mass transportation.
- Governments can require the coordination of energy supply and energy use planning and investment such that cogeneration and district heating systems are expanded.
- Governments can set taxes to ensure that new dispersed developments pay the full costs they cause to energy and water utilities, transportation services, urban livability, and the environment.

These community energy management policies are relevant to all countries. However, it must be recognized that developing countries face special challenges because of rapid rates of urbanization and the lack of institutional, professional, and financial capacity to perform the tasks required – i.e., planning, zoning, and regulation, as well as developing adequate infrastructure for energy, water, sewage, transportation, and other potential collective services, like district heating and cooling. Thus, in developing countries energy efficiency in urban planning would include the following:

- Policies to support local planning, control, and perhaps ownership (municipal utilities, co-operatives, local entrepreneurs) of energy and other utility networks. This has been shown to reduce line losses due to theft and thus improve the operating efficiency of the grid.
- Policies are needed to provide mechanisms for municipal financing and micro-financing of local developments and improvements to infrastructure for energy and energy-related services like transportation, water, and sewers by using efficient technologies that reduce energy and other operating costs. These policies would include support for more effective public investment, which may be leveraged and managed to increase private investment through ensuring stable and sufficient returns on capital.

22.3.2.5 Energy Efficiency Policies for Transportation[8]

A key aspect to developing effective transportation energy efficiency policies is to integrate individual policies and regulations into packages that benefit from a synergistic interaction among the components. Two types of policy portfolios can improve the overall energy efficiency of private transportation. In the case of personal transportation, the first portfolio approach consists of policies that improve vehicle fuel efficiency. The second consists of policies aimed at reducing private vehicle travel and increasing the use of public transit, walking, and cycling within cities and of trains for long distance travel. In the same vein, with the transport of goods, one approach is to make trucks, trains, boats, and planes more efficient. While another approach is to encourage mode shifting to the mode that is most energy efficient for a particular mobility need.

It should be noted that policies to improve vehicle and transport equipment efficiency can work in opposition to policies to encourage mode shifting. More efficient vehicles have lower operating costs and become even more attractive relative to alternatives. This is why vehicle efficiency policies need to be combined with policies that keep the cost

8 For more on energy and transport, see Chapter 9.

of vehicle use high by reflecting congestion costs (road pricing), environmental effects (emissions pricing), and urban livability (vehicle-free streets, parking charges, parking restrictions, vehicle registration fees).

- Governments can set vehicle efficiency regulations. Such regulations can apply universally to all vehicles or can be flexible by allowing different levels of efficiency, as long as vehicles collectively achieve an average level of efficiency. This latter is the case of the Corporate Average Fuel Economy (CAFE) Standards introduced in the United States in 1975.

- Governments can use financial penalties and financial incentives alone or in combination. In the latter case, a feebate policy levies a one-time or annual charge on less efficient vehicles and uses the resulting revenue to provide a one-time or annual subsidy to efficient vehicles.

- Governments could guarantee to purchase the most efficient vehicles for their own vehicle fleets, thereby providing a guaranteed market for the next generation of new vehicles.

- Local governments can implement road pricing to reduce vehicle use and urban congestion. This may include tolls on key bridges or highways, or an electronic zonal pricing system covering a major urban agglomeration. In the case of tolls on bridges and highways, a reduced or zero rate for high-occupancy vehicles encourages more passengers per vehicle and thus a more efficient vehicle use rate. Local and regional governments should make sure that private vehicles on roads face tolls that reflect the costs they incur, including environmental and human health externalities.

- Governments can require vehicle insurance companies to charge distance-based insurance rates, determined by annual odometer readings.

- Governments can rationalize traffic signals to optimize vehicle traffic flows.

- Government regulations can set efficiency standards for modes of transport of goods (trucks, trains, boats, planes). These can have design flexibility similar to that outlined above for personal vehicles.

- Government regulations and pricing can foster modal shifting toward more energy efficient modes of transport of goods, such as a shift from trucks to trains, when possible.

22.3.2.6 Energy Efficiency Policies for Agriculture

Agriculture can be energy intensive, especially the industrialized version practiced today in many parts of the world. Direct energy use in agriculture results from farm equipment, buildings, irrigation, and post-harvest processing. Indirect energy use in agriculture results from the production of fertilizers and pesticides. In the United States, about a third of all energy used in agriculture relates to commercial fertilizer and pesticide production. Potential energy savings in the agricultural sector can be achieved through changes in on-site transportation, reduced tillage, and improvements in irrigation, drying, dairy and livestock production, and horticulture, among others.

- Governments can provide information, low interest loans, and grants to foster the use of more efficient technologies and techniques in agriculture. But as with all subsidies, care must be taken not to provide support that has little effect because it pays farmers for efficiency measures they would have undertaken anyway.

- Governments can provide training for farmers and farm personnel in ways of reducing energy use.

- Governments can tighten regulations on some types of agricultural practices, such as irrigation technologies, pesticide use, and herbicide use, in ways that would indirectly reduce energy use.

- Governments and utilities can change tariff structures to encourage energy efficiency in all farming practices.

- Governments can levy taxes on fertilizers and on fuel for tractors.

22.3.2.7 Decentralized Energy Policies and Energy Efficiency

The human population is urbanizing rapidly. Cities are now responsible for two-thirds of total primary energy use. As demand for energy services continues to grow, the energy infrastructure that cities depend on will need to be expanded, upgraded, or replaced. This provides governments with opportunities to build energy efficiency or reduced energy service demands into long-lived infrastructure, plants, and equipment. This includes everything from urban form, to energy supply, to major energy end-uses.

Expanding, upgrading or replacing energy infrastructure also presents an opportunity to move toward more decentralized, low emission energy systems. Decentralization may contribute to the goal of low cost energy access with a minimum of negative social and environmental impacts. At the same time, local awareness of energy supply can increase, and that can foster a greater emphasis on energy efficiency.

Decentralized energy systems include locally-focused mini-grids that connect small-scale local supply with local demand and energy self-sufficient industries. Decentralized energy systems can reduce the need for expensive, expansive energy grids and increase the reliability of the system. It can also provide reliable energy to communities currently not connected to the grid.

Government at all levels can support the development of smaller-scale, local energy supplies. Support can come via implementation of incentives, such as tax advantages, regulatory flexibility for municipalities and utilities to encourage distributed and decentralized energy supply, and grants and low-interest loans for feasibility studies and capital costs related to development of district energy systems. Governments must also support knowledge- and technical capacity-building. Local governments should be involved in the development of decentralized energy systems because they often build, own, and operate decentralized energy systems. The following policies can contribute to decentralized energy supply:

- Development permit area guidelines can require decentralized renewable energy systems external to buildings, such as the installation of ground-source heat pump systems, to reduce total energy use.
- Tax exemptions for development projects using local renewable energy sources can be incentives to owners and developers to promote decentralized energy retrofits on buildings or neighborhood-scale initiatives. This might include solar water heaters, heat pumps, or heat recovery systems.
- Development cost charge (DCC) reductions or exemptions, conditional on inclusion of decentralized energy generation, can provide financial incentive for developers.
- Local governments can adopt a rezoning policy that encourages decentralized energy generation in new developments. Such a policy would indicate clearly which attributes will be sought by governments when making rezoning decisions, creating incentives for developers to include decentralized energy in their plans.
- Local improvement charges can promote the use and finance the installation of renewable energy systems in existing buildings and developments throughout a community. For instance, these can be used to pay for the installation of solar hot water systems in the community.
- Local governments can use service area bylaws to provide, and charge for, decentralized energy generation and services.
- Governments can enact regulations that require renewable technologies, like solar water heating or rooftop photovoltaic systems on new buildings.
- Local governments can offer or expropriate land for the construction of local energy generating plants.
- Electric utilities can adjust their grid extension policies so that communities that are beyond eligibility for grid connection receive technical and some financial support to develop mini-grids. Public-private partnerships of various types may be effective in this area.
- Developed countries should promote the transfer of new technologies related to decentralized energy to developing countries.
- Utility regulators need to adopt flexible, lighter approaches to utility regulation so that small-scale operations that are nonetheless defined as utilities – such as the provision of energy supply to a building, a development, a group of buildings, or a remote community – do not face the typical regulatory burdens of conventionally-sized utilities.
- International and national aid agencies may want to focus energy-related aid efforts into supporting with capital and expertise the development of decentralized energy systems in developing countries. But care should be taken so that this does not come at the expense of expanding large-scale systems, if that is more cost effective.

22.3.3 Linking Policies and Investments

It is sometimes assumed that one can measure a policymaker's commitment to a particular issue by the amount of public funds they are willing to commit. In the case of energy policy, this assumption would be misleading in some instances. Good energy policy can sometimes require little or no expenditures, as in the case of effectively managing and regulating the interplay of monopolistic and competitive forces in the electricity sector or effectively managing a valuable resource endowment. However, when it comes to the rapid expansion of the energy sector necessary to provide adequate energy access to billions of un-served and under-served people, and to the much-needed transformation of the global energy system to one with a much smaller environmental impact, effective energy policies will need to stimulate a great deal of investment from the public and especially the private sector.

Chapter 22 emphasizes the need to price harmful energy-related emissions so that energy prices reflect environmental costs. Properly pricing energy to include the value of environmental harms and risks can drive massive investments in cleaner energy technologies and in energy efficiency. Chapter 24 describes a slate of policies that can create an enabling environment for profound energy technology system innovation. But these policies will be especially effective in developed countries where lack of energy access is less of an issue. In developing countries, policy must also result in a profound investment in energy supply.

Chapter 6 describes the types of investments that are required for the global energy system. Chapter 17 links the magnitude of these investments to specific pathways in terms of potential development of energy efficiency and the expansion of energy supply from renewables, nuclear

Table 22.2 | Investment needs and policy mechanisms.

	Investment (billions of US$/year)		Policy mechanisms			
	2010	**2010–2050**	**Regulation, standards**	**Externality pricing**	**Carefully designed subsidies**	**Capacity building**
Efficiency	n.a.[1]	290–800[2]	*Essential* (elimination of less efficient technologies every few years)	*Essential* (cannot achieve dramatic efficiency gains without prices that reflect full costs)	*Complement* (ineffective without price regulation, multiple instruments possible)[3]	*Essential* (expertise needed for new technologies)
Nuclear	5–40[4]	15–210	*Essential* (waste disposal regulation and, of fuel cycle, to prevent proliferation)	*Uncertain* (GHG pricing helps nuclear but prices reflecting nuclear risks would hurt)	*Uncertain* (has been important in the past, but with GHG pricing perhaps not needed)	*Desired* (need to correct the loss of expertise of recent decades)[5]
Renewables	190	260–1010	*Complement* (renewable portfolio standards can complement GHG pricing)	*Essential* (GHG pricing is key to rapid development of renewables)	*Complement* (feed-in tariff and tax credits for R&D or production can complement GHG pricing)	*Essential* (expertise needed for new technologies)
CCS	<1	0–64	*Essential* (CCS requirement for all new coal plants and phase-in with existing)	*Essential* (GHG pricing is essential, but even this is unlikely to suffice in near term)	*Complement* (would help with first plants while GHG price is still low)	*Desired* (expertise needed for new technologies)[5]
Infrastructure[6]	260	310–500	*Essential* (security regulation critical for some aspects of reliability)	*Uncertain* (neutral effect)	*Essential* (customers must pay for reliability levels they value)	*Essential* (expertise needed for new technologies)
Access[7]	n.a.	36–41	*Essential* (ensure standardization but must not hinder development)	*Uncertain* (could reduce access by increasing costs of fossil fuel products)	*Essential* (grants for grid, microfinancing for appliances, subsidies for cooking fuels)	*Essential* (create enabling environment: technical, legal, institutional, financial)

1. Global investments into efficiency improvements for the year 2010 are not available. Note, however, that the best-guess estimate from Chapter 24 for investments into energy components of demand-side devices is by comparison about 300$ billion per year. This includes, for example, investments into the engines in cars, boilers in building heating systems, and compressors, fans, and heating elements in large household appliances. Uncertainty range is between US$100 billion and US$700 billion annually for investments in components. Accounting for the full investment costs of end-use devices would increase demand-side investments by about an order of magnitude (see Chapter 24 for details).
2. Estimate includes efficiency investments at the margin only and is thus an underestimate compared with demand-side investments into energy components given for 2010 (see note 1).
3. Efficiency improvements typically require a basket of financing tools in addition to subsidies, including, for example, low- or no-interest loans or, in general, access to capital and financing, guarantee funds, third-party financing, pay-as-you-save schemes, or feebates as well as information and educational instruments such as labeling, disclosure and certification mandates and programs, training and education, and information campaigns.
4. Lower-bound estimate includes only traditional deployment investments in about 2 GW capacity additions in 2010. Upper-bound estimate includes, in addition, investments for plants under construction, fuel reprocessing, and estimated costs for capacity lifetime extensions.
5. Note the large range of required investments for CCS and nuclear in 2010–2050. Depending on the social and political acceptability of these options, capacity building may become essential for achieving the high estimate of future investments.
6. Overall electricity grid investments, including investments for operations and capacity reserves, back-up capacity, and power storage.
7. Annual costs for almost universal access by 2030 (including electricity grid connections and fuel subsidies for clean cooking fuels).

power, and perhaps fossil fuels, provided that emissions can be captured and safely stored. The following table from Chapter 17 summarizes, in a very general way, the link between policies and investment levels.

Detailed information on this table is provided in Chapter 17. Here we simply reiterate a few key points. The energy investment columns refer to investment levels needed for different pathways. Thus, a high-energy efficiency pathway would require over US$500 billion/year of new investment. In contrast, since there are pathways in which nuclear power stagnates, its annual investment could be as low as US$15 billion/year, a sharp contrast with the almost US$400 billion/year for an energy pathway that includes a substantial role for nuclear power. In the same vein, CCS could be abandoned in some energy pathways, while in others its rapid adoption could require almost US$100 billion/year of new investment.

The policy mechanisms of the table provide an admittedly crude simplification. There are only four policy types (regulations, pricing, subsidies, capacity building) and their role and relationship to each other is evaluated in only four ways (essential, complement, desired, uncertain). In reality, there are many variations within these four policy types, and indeed, there are policies that are hybrids in combining elements of both.

Likewise, depending on how they are designed and implemented, some policies can be complements in some cases and substitutes in others.

With these caveats, the investment table nonetheless provides a summary of the amount of investment required under various energy pathways and kinds of policies needed to drive this investment. In so doing, it gives a general sense of points made throughout this chapter, namely that: (1) strong pricing and regulatory policies will be required for the major energy transitions called for in GEA; and (2) policy coordination is essential for this effort to be effective.

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