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Renewable Energy Innovation Policy:
Success Criteria and Strategies

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About IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international cooperation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity. www.irena.org.

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Disclaimer:

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List of Acronyms

BRIC	Brazil, Russia, India and China (economic grouping)
CSP	Concentrating solar power
EDC	Energy Development Corporation (Philippines)
EE	Energy efficiency
FDI	Foreign direct investment
GHG	Green House Gas
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
IRES	Indonesian Renewable Energy Society
LCOE	Levelised cost of energy
MWh	Megawatt-hour
NOx	Nitrogen oxides
OECD	Organisation for Economic Co-operation and Development
RD&D	Research, development, and demonstration
RE	Renewable energy
RET	Renewable energy technology
SOx	Sulphur oxides
WRI	World Resources Institute

EXECUTIVE SUMMARY

Excelling at renewable energy technology (RET) innovation is an important aspiration for many nations. Yet, at the national and sub-national level, responsibility for the development of renewable energy innovation policy is typically distributed across multiple stakeholders with diverse interests, and policy options are constrained by existing economic, institutional, and social factors. These barriers to coherent renewable energy innovation policy development may be overcome by aligning accompanying strategies with broader energy development goals, and by expanding the network of stakeholders beyond renewable energy itself. This report aims to establish an analytical process to clarify contextual determinants of RET innovation and promote durable, coherent renewable energy innovation policy development across a wide range of national and sub-national contexts.

The report identifies broad success criteria for renewable energy innovation policy and suggests strategic policy orientations to advance RET innovation in the context of constrained options, competition for resources, and national economic development goals. Successful renewable energy innovation policy regimes meet two broad criteria:

- They promote sustained multi-stakeholder engagement around an achievable, shared vision; and
- They appropriately position a country or region to anticipate and benefit from renewable energy technology flows.

These criteria reflect two general features of innovation itself. The first is that because innovation arises from a complex mix of social, financial, and technical factors, responsibility for innovation policy is naturally distributed across many institutions and actors. Thus, success will be promoted insofar as innovation policy discussions are integrated into existing macro-level policy and economic goals, providing a level of stability and coherence that might otherwise be lacking. The second feature is that innovation cannot typically be mandated, but rather must be enabled, and so policy-makers face the challenge of cultivating *innovation capacity.* Consequently, a key indicator of innovation policy success is growth in the ability of a nation or region to anticipate and benefit from flows of technology, accumulate stocks of knowledge and social capital, "learn how to learn," and shift the rates of productivity and technological accumulation.

Since there is a wide range of technological maturity across the landscape of renewable energy technologies, it is important to recognise the different types of innovation that promote RET deployment. This report discusses three distinct types – or modes – of RET innovation: *technology venturing, commercial scale-up, and adaptation*. An understanding of these RET innovation modes can support accurate assessment of innovation capacity requirements and the development of targeted policies to support innovation capacity growth.

An important component of strategic renewable energy innovation policy development is to target specific technologies of interest from among the diversity of potential RET system configurations. This objective can be supported by situating such policy development within broader energy development goals, which strongly influence stakeholder networks and future technology flows. Attention to energy development goals also provides a basis for identifying likely innovation modes and the corresponding determinants of innovation capacity. Six energy development goals that, either alone or in combination, commonly shape energy development pathways, are identified. They are:

- Energy Security;
- Energy Access;
- Energy Cost;
- International Competitiveness;
- Modernisation; and
- Green House Gas (GHG) emissions reduction.

The report provides a brief discussion of how these goals can inform innovation policy development, and concludes with a step-wise process towards developing strategic renewable energy innovation policy frameworks:

1. Identify the energy development goal(s) within the region of interest;

2. Characterise the likely technology flows associated with these goals;

3. Identify the types of innovation activities that are appropriate for accelerating these technology flows;

4. Assess the innovation capacity needs necessary to achieve these innovation activities; and

5. Identify and convene the likely set of stakeholders involved in promoting policies to meet these innovation capacity needs.

RET innovation capacity is the product of many factors that vary widely across national and sub-national contexts; especially the economic, cultural, and political ecosystems in which RETs are deployed and in which policy is developed. While attention to general principals of innovation can improve policy-making, sensitivity to a broad range of contextual variables is likely to be more important in the domain of renewable energy innovation policy than in conventional innovation policy-making. This report aims to advance an approach that prioritises contextual awareness with the goal of promoting improved RET innovation and deployment outcomes.

1. INTRODUCTION

Renewable energy technology (RET) will play a key role in the UN Secretary General's Sustainable Energy for All Initiative objectives of (i) ensuring universal access to modern energy services, (ii) doubling the global rate of improvement in energy efficiency, and (iii) doubling the share of renewable energy in the global energy mix, all by 2030. Continuing cost reductions in existing RETs will help achieve each of these goals, although further innovation will also be required. In the case of improving energy access globally, the significant cost and complexity of building out conventional electrical grids may slow the adoption of those RET systems which rely on grid connection, as many commonly do. In the case of achieving low-carbon energy systems, systematic economic analysis suggests that, even with significant cost reductions, widespread deployment of currently available RETs will not be sufficient[1]. Rapid deployment of current technologies, along with continuous technological innovation and commercialisation, will be required to achieve stated emissions targets.

Given that many look to RET innovation to help mitigate problems of energy security, energy poverty, or climate change, the key question for policy-makers is *how to promote RET innovation*. While more than three decades of global RET market growth have provided a clearer picture of what RET innovation looks like, so too has a clearer picture emerged of the barriers to widespread RET deployment. These barriers are intuitive to RET entrepreneurs, and are well-researched in the literature. They include technology cost disadvantages relative to conventional sources of energy; multiple externalities (both positive and negative); infrastructure lock-in; engrained consumer habits; and resistance from well-established conventional energy firms. These barriers strongly influence the options that are available to scientists, entrepreneurs, and policy-makers in the clean energy domain.

Beyond these deployment constraints, policy-makers themselves face a set of barriers to crafting coherent, sustained RET innovation policy. Crafting any innovation policy for a specific industrial class – whether agricultural products or tablet computers – is a particularly complex task. On one hand, this is due to the nature of innovation itself, which is a fluid, non-linear process, springing from a mix of human ingenuity, private sector initiative, codified and tacit knowledge, networks of financial resources, intelligent management, and a measure of good timing. Given these qualities, innovation remains a policy goal that cannot be mandated, but rather must be *enabled*. On the other hand, structural factors (such as limited budgets, competing policy priorities, political turnover, data quality, and dynamic technological change) all complicate the three stages of policy-making: design, implementation, and evaluation. Many governments face genuine challenges in providing long-term policy stability under such constraints.

In light of these constraints, this report describes a policy development framework designed to align RET innovation policy-making with enduring themes of national energy development. The report is organised as follows:

- Section 2 provides a broad overview of RET innovation concepts and definitions.
- Section 3 provides a taxonomy of RET innovation policies and policy functions, and a discussion of some key topics in RET innovation policy development.
- Section 4 discusses five types of energy development goals that inform technology flows and stakeholder networks across a wide range of national contexts.
- Section 5 concludes by suggesting a step-wise process for promoting coherent renewable energy innovation policy development.

2. INNOVATION CONCEPTS AND DEFINITIONS

Innovation in the domain of renewable energy technologies shares many similarities to innovation in other sectors, but it is also unique in important ways. A useful definition of innovation provided by the Organisation for Economic Co-operation and Development (OECD) identifies four unique categories:

Product innovation involves a good or service that is new or significantly improved. This includes significant improvements in technical specifications, components and materials, incorporated software, user-friendliness or other functional characteristics.

Process Innovation involves a new or significantly improved production or delivery method. This includes significant changes in techniques, equipment and/or software.

Marketing Innovation involves a new marketing method involving significant changes in product design or packaging, product placement, product promotion or pricing.

Organisational Innovation involves introducing a new organisational method in the firm's business practices, workplace organisation or external relations.[2]

Each of these innovation types is relevant for RETs although, as discussed below, the latter types are less relevant for early-stage RETs that have not yet achieved significant commercial adoption.[1] Specific case studies of RET innovation can illustrate the progression of these innovation types over time, ranging from breakthroughs in basic science to rural adaptations of integrated solar systems; from incremental cost-saving improvements in materials and labour to streamlined business models that speed deployment in markets. When successive innovations unfold and reinforce each other over time, as they have in the cases of wind and silicon photovoltaic (PV) technologies, the result is a parallel progression of cost reductions and deployment gains, as illustrated in Figure 1.

The capacity to innovate arises from social interactions between people, and these interactions are most commonly cultivated within a commercial enterprise, or "firm". However, "non-firm" actors are essential contributors to innovative capacity.[4] Non-firm actors include, but are not limited to, universities, national research laboratories, standards bodies, and industry groups. While innovation capacity is rooted in specific social networks, innovation networks and activities change over time in relation to the maturity of the technology in question. The types of innovation activities taking place in silicon computer chips in the years 1961 and 2011 for example, and the specific social networks in each era, were closely related to the commercial and technological maturity of the industry at those moments in time. Similarly, the activities and networks giving rise to PV innovation in 2012 are distinct from those in 1982.

The maturity of a particular technology can be illustrated within the figurative space of cost and total deployment. Within this two-dimensional space, the life cycle of a technology can be divided into five broad stages: *basic science and research and development (R&D), applied R&D, demonstration, market development,* and *commercial diffusion*. These stages are useful insofar as they help contextualise the types of innovation activities that are possible and necessary to advance a given technology at a given time, and determine which types of policy instruments might be appropriate to a technology at a specific stage of risk and maturity.[2] Figure 2 illustrates these stages.

Three broad classes of RET innovation activities – innovation "modes" – are relevant for policy consideration. Other types of innovation are described in the literature, and the classes presented here should not be taken as

1 It is also useful to distinguish innovation from invention. An invention may be an idea, model, or sketch of a device, product, or process; in contrast, an innovation occurs when a device, product, or process is involved in a commercial transaction. These distinctions were first articulated by Joseph Schumpeter in *Capitalism, Socialism, and Democracy* (Harper Perennial, 1962), and they are discussed in detail by Narula (2003). Globalisation and Technology: Interdependence, Innovation Systems and Industrial Policy, Cambridge, Polity Press. A particular innovation may be a product of several inventions, and so the ability to transfer invention to innovation is an important capability in itself.

2 Real-world processes of innovation entail significant feedback loops between these different stages, and the boundaries between them are permeable.

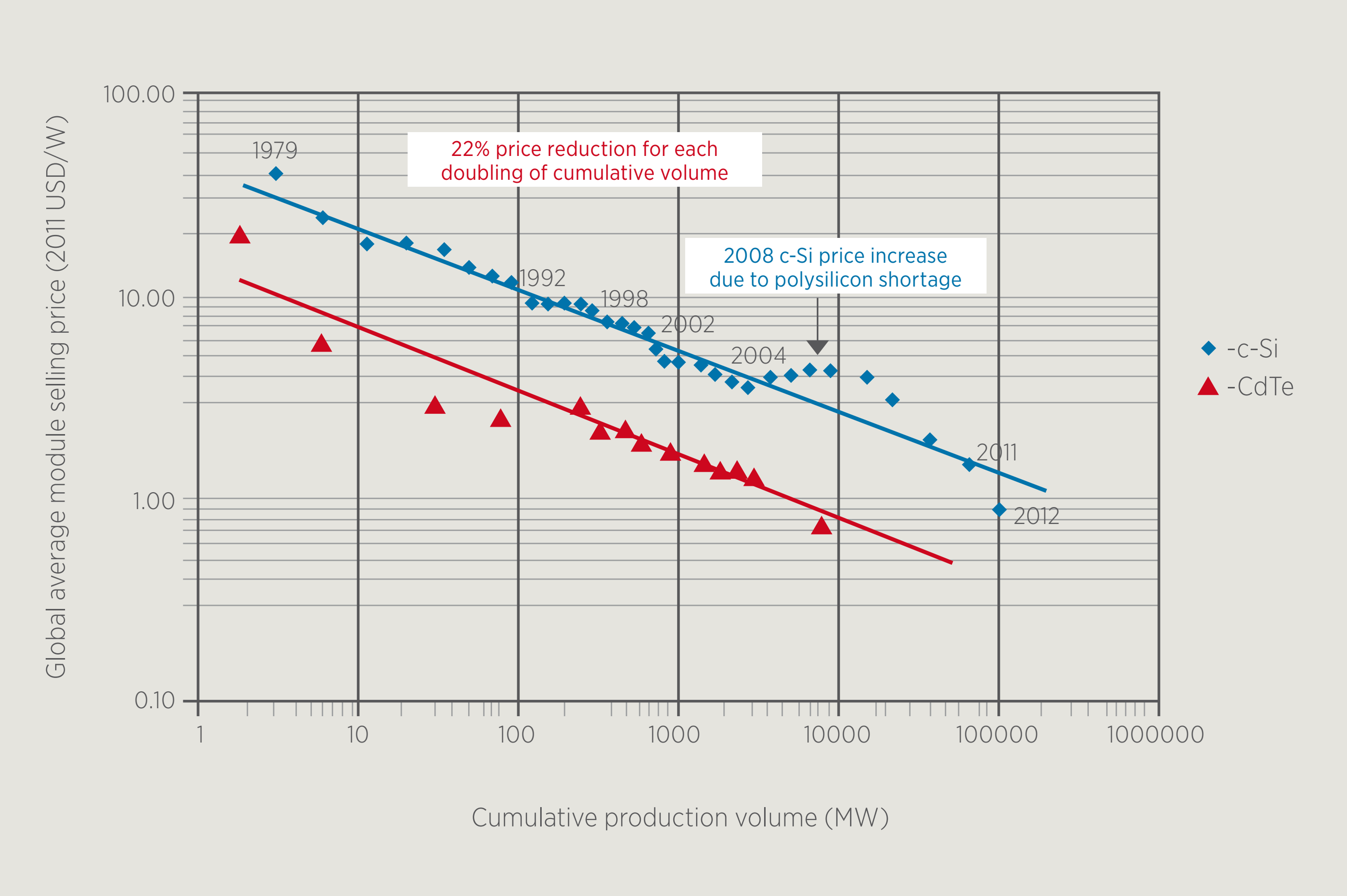

FIGURE 1: DECLINE IN PV MODULE PRICES [3]

an exhaustive description of the innovation modes available to a firm or a country. Rather, they represent three key classes of activity that policy-makers can reference to structure policies and supporting programmes.

» *Technology Venturing*: Technology venturing encompasses efforts to move a particular technology or system from the R&D stage to the demonstration stage, typically by establishing a firm and securing financing, or by licensing a technology to an existing firm. This type of innovative activity usually occurs at the "technology frontier"; involves the manufacture of novel systems, materials, or both; and is typically highly research- and capital-intensive. Current examples include efforts to demonstrate multi-junction PV cells, "third-generation" biofuel production systems, and utility-scale tidal power systems.

» *Commercial Scale-up*: Commercial scale-up encompasses efforts to move a technology from the demonstration phase to commercial readiness. This type of innovative activity typically occurs after successful demonstration projects have been completed but before major mainstream success has been achieved. Within a conglomerate firm, this stage encompasses scaling up a specific RET product line. In start-up firms, this stage encompasses activities involved in overcoming the "valley of death" – the period of low or uncertain cash flows that occurs after initial venture funding has peaked, but before commercial transactions can sustain an individual firm. While still requiring technical innovation, these activities also involve a high degree of business development, including regular interaction with customers, suppliers, financial institutions, and insurers. Current examples of this domain of innovation include efforts to grow the markets for utility-scale concentrating solar power systems and "second generation" biofuel production facilities.

» *Adaptation*: Adaptation encompasses efforts to introduce existing commercial technologies into new markets. For example, deploying commercially available solar PV technologies on a remote Pacific island brings novel challenges

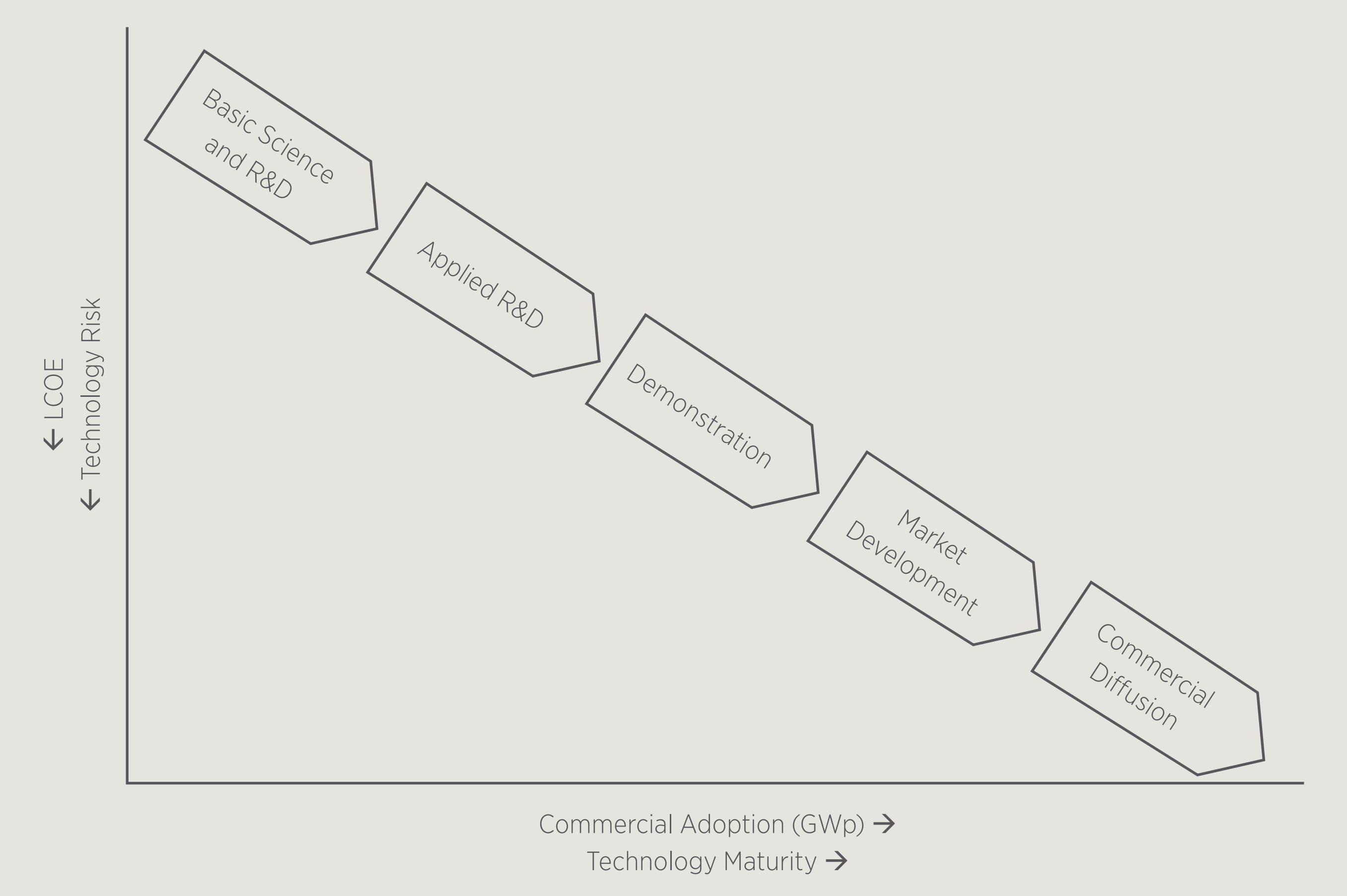

FIGURE 2: STAGES OF THE INNOVATION PROCESS WITHIN THE MATURITY SPACE

that themselves require innovation, albeit of a less scientific nature than technology venturing does. Innovation at this stage typically involves novel marketing, business models, or financing structures, tailored systems integration expertise, and the formation of tacit knowledge gained through system installation and maintenance.

These three RET innovation modes are illustrated within the technology maturity space in Figure 3. For low- and middle-income countries, policies to support knowledge- and capital-intensive activities in the early stages of technology maturity – the "technology frontier" – are generally less feasible than policies that encourage RET deployment and corresponding technology transfer opportunities. Thus, this report tends to focus on strategies to leverage later-stage deployment opportunities in a manner that accelerates the growth of innovation capacity and aligns with broader energy development goals (discussed in Section 4).

The concepts outlined in Figures 2 and 3 provide a general framework to assist policy-makers in understanding the relative maturity of RETs and their corresponding innovation modes. These concepts will be useful in clarifying the perspective of potential innovators and entrepreneurs, and in determining the types of innovation capacity that are appropriate for specific regional contexts, both of which are vital concerns for effective renewable energy innovation policy. Section 3 discusses the landscape of RET policy options, and some of the critical issues associated with implementing strategic innovation policy portfolios.

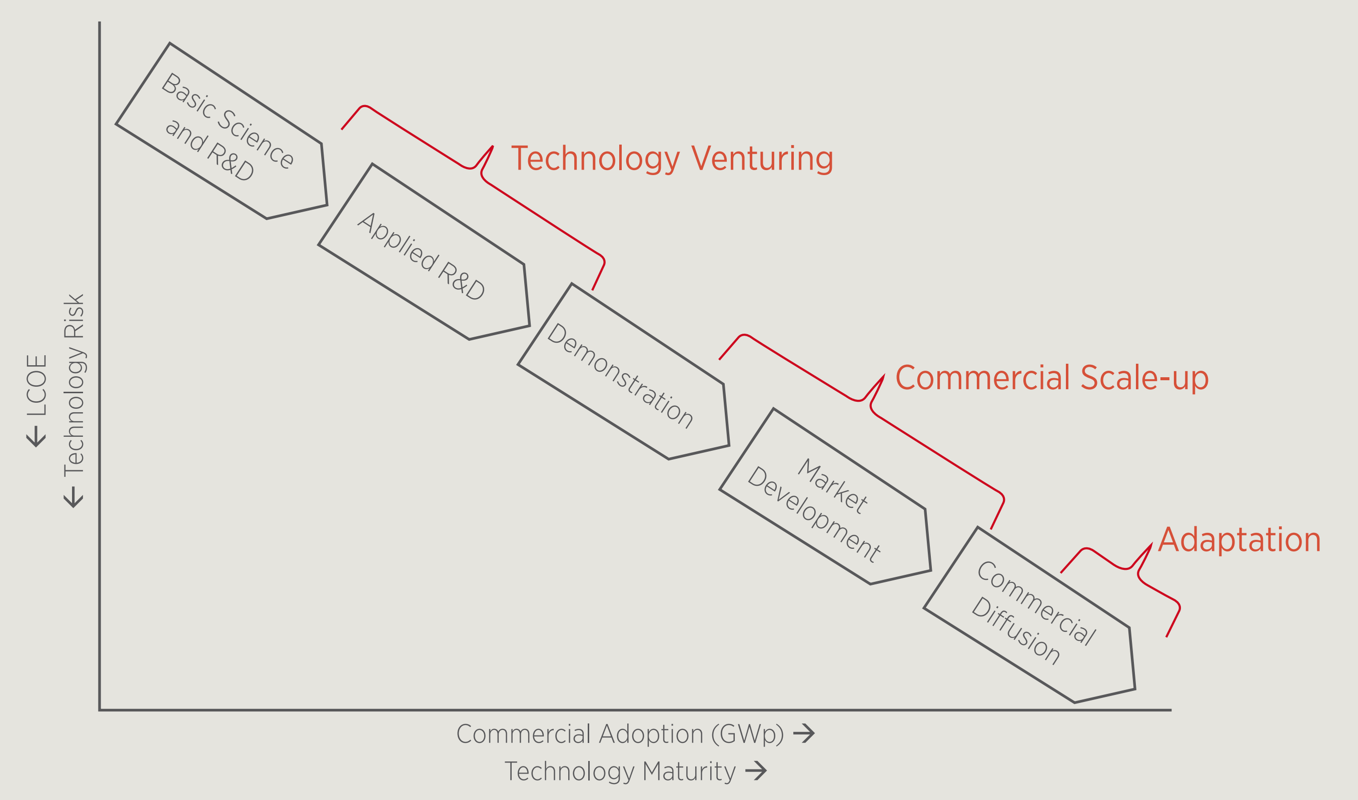

FIGURE 3: RET INNOVATION MODES WITHIN THE MATURITY SPACE

3. RET INNOVATION POLICY

Globally, many policy instruments have been developed with the goal of accelerating RET deployment and innovation. An extensive database containing examples of policies and measures is accessible online through a website maintained by the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA),[5] while updates of *deployment* policy instruments are provided in the annual *Global Status Reports* from the Renewable Energy Policy Network for the 21st Century (REN21).[6] Policy instruments in support of technological innovations may include financial support for university research consortia, government-sponsored R&D laboratories, and public-private applied R&D partnerships. Policy instruments to help move these technologies to market may include technology transfer programmes; grants for pilot projects; loan guarantees and other financial instruments for constructing demonstration plants; and industry collaborations to promulgate standards or ensure technology interoperability. Each of these policies serves a specific function for the region or country in question. We adopt the World Resources Institute (WRI) policy "toolbox" to broadly describe the set of instruments at the disposal of policy-makers (see Table 1). Tools are categorised by the function performed by each policy.

This broad taxonomy of functions indicates the breadth of roles that governments can play to create and sustain a functioning "innovation ecosystem."[8] Some policies are important, regardless of technology type or maturity. However, technologies at various stages of maturity generally respond better to some policies than to others, and therefore an understanding of comparative technology maturity is useful for selecting policy instruments.

The functions and tools from Table 1 can be roughly mapped within the maturity space described in Figure 2, with the y-axis denoting cost and technology risk, and the x-axis representing deployment. When combined with a figurative representation of technology development stages, the result is shown in Figure 4.

Looking at the innovation policy toolbox within the maturity space reveals several relevant features. First, certain functions and tools apply broadly across all stages of innovation – namely *Building Competence and Human Capital, Creating and Sharing Knowledge,* and *Knowledge Diffusion/Creating Collaborative Networks*. These functions cultivate the human, social, and intellectual capital that sustains innovative ecosystems. The most basic form of this level of policy is a standard role for government – maintaining educational systems through university and graduate levels. Impacts of such educational investments are not restricted to RET innovation capacity alone – indeed, they are the activities

Table 1: Innovation functions and examples of policy tools[7]

Function	Example Policy Tools
Creating and Sharing New Knowledge	Subsidies and incentives for new research, contests and prizes, intellectual property protection and enforcement measures.
Building Competence and Human Capital	Subsidies and incentives for education and training, fellowships, scholarships, and visas for advanced degree candidates.
Knowledge Diffusion / Creating Collaborative Networks	Joining or initiating international cooperation, supporting industry associations, intellectual property protection and enforcement measures that provide confidence for network participants.
Developing Infrastructure	Public-private partnerships, incentivising private development, planning for public development, and investment in public infrastructure.
Providing Finance	Loan guarantees, "green" banks, and public venture capital-style funds.
Establishing Governance and the Regulatory Environment	Setting standards, setting targets, taxing negative externalities, subsidising positive externalities, eco-labeling and other voluntary approaches, and tradable permits.
Creating Markets	Feed-in tariffs, renewable portfolio standards, government/public procurement, media campaigns, setting government requirements, taxing negative externalities, subsidising positive externalities, eco-labeling, and other voluntary approaches.

most likely to "spill over" and produce novel capabilities and entrepreneurship across the economy.[9] More targeted knowledge development and human capital activities, such as fellowships, renewable energy resource assessments, or industry associations, impact on human capital and innovation capacity more narrowly.

Other functions and tools are more appropriate for technologies poised to graduate into the stages of demonstration and market development, specifically *Establishing Governance and the Regulatory Environment, Developing Infrastructure, Providing Finance, and Creating Markets*. Because these policies are generally designed to address specific market failures or issues of technology lock-in,[10] their design more narrowly applies to mature technologies, and their impacts are more likely to be restricted to the energy sector as opposed to spilling over into other technology areas.

The constellation of RETs is dispersed across the space of cost, technology risk, and commercial adoption, with important variations in each country and even within grid systems. For example, the installed cost of a 4kW solar PV system ranges from USD 7 000 in Portugal to USD 3 000 in India.[11] Additionally, social and cultural barriers to RET deployment may vary quite widely between countries, significantly impacting on cost. For example, the social costs of large-scale hydropower can be high, requiring the relocation of entire villages, and these costs may be acceptable in some countries, although not in others.

The Levelised Cost of Electricity (LCOE) of RETs depends on a wide range of factors, and can vary widely between regional contexts. In support for greater transparency of actual costs, the IRENA carries out a series of renewable energy technologies cost analysis studies that aim to provide accurate information to consumers, project developers, investors, and policy-makers around the world. The current assessment of LCOE for different RETs (Figure 5) acknowledged variations which depend not only on the local resource potentials and deployment capacity but also on the relative maturity of technologies. For example, technologies that are in the domains of R&D and applied R&D such as ocean thermal energy and organic PV would have high LCOE and technology risks, whereas those in the demonstration to market development stages, including Concentrating Solar Power (CSP), offshore wind and thin film PV have lower LCOE and technology risks.

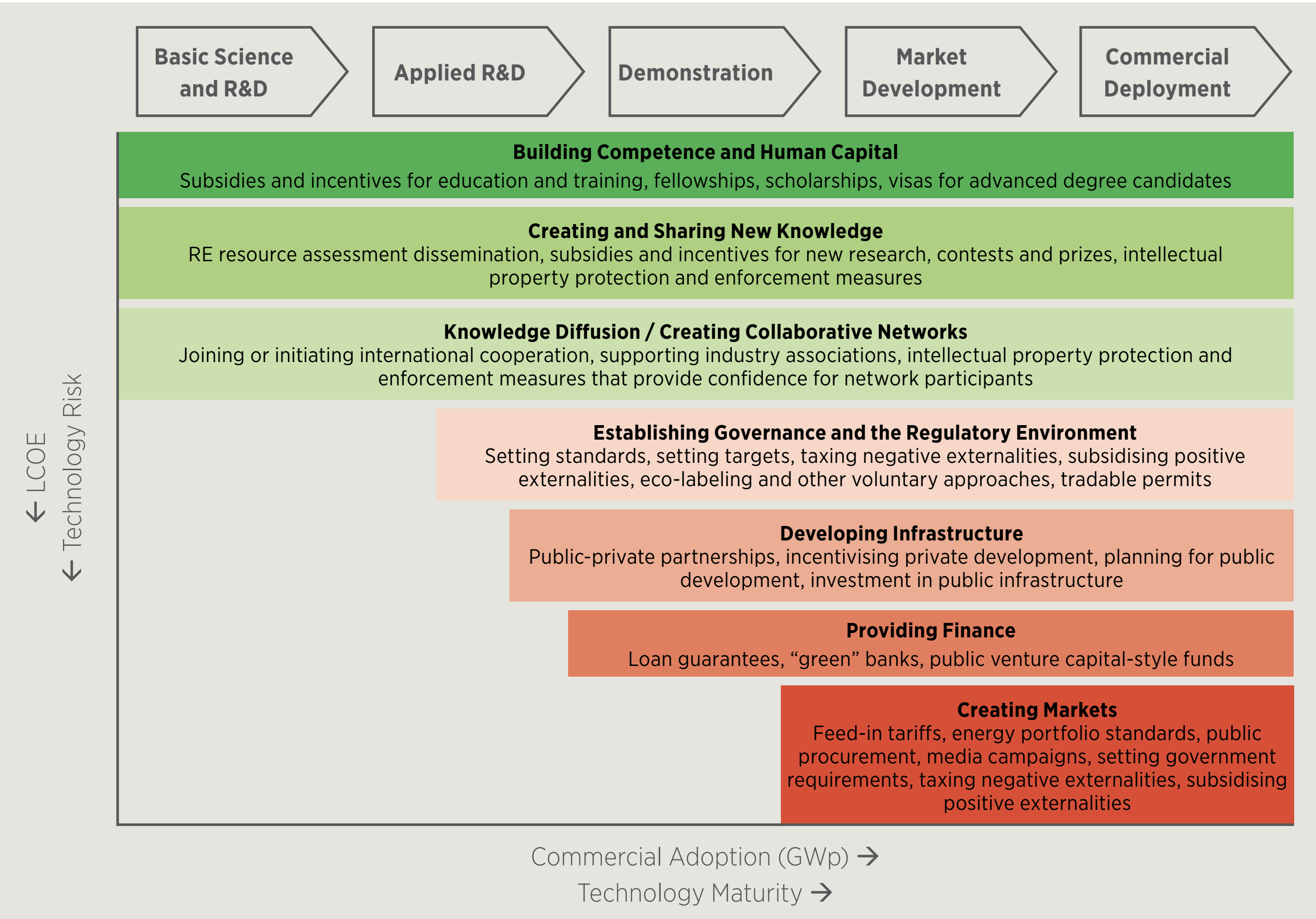

Figure 4: Policy functions and tools mapped within the technology maturity space

The ways in which these technologies interact with existing markets, grid systems, and infrastructure bases also vary widely. Consequently, no single policy will spur deployment and innovation equally well across national contexts or technologies. Additionally, deployment and innovation policies often interact with each other and with existing policies in ways that are difficult to predict. For this reason, achieving optimal configuration and timing of innovation policies is a practical problem that deserves thorough attention. In an attempt to move in this direction, the following sections briefly discuss some key issues involved in renewable energy innovation policy development.

3.1. Making Policy in a "Second Best" World

RET innovation policy presents two distinct challenges for policy-makers: providing the right enabling conditions for innovation to flourish, and doing so consistently for many years. Addressing these two challenges is an important concern when identifying success criteria and strategies for renewable energy innovation policy. And yet, faced with imperfections in the marketplace, the elusive nature of innovation itself, and structural constraints on the development of RET innovation policy, real world innovation policy may tend towards opportunistic improvisation rather than sustained, long-term, and comprehensive national visions. While the latter would be preferable, policy-making contexts are typically defined by limited resources, dynamically evolving priorities, democratic elections, and free markets, thus making long-term focus and commitment difficult to sustain. Accordingly, efforts to support RET innovation are often rooted in specific projects, and follow networks of business acquaintance and domain-specific technical collaboration. While such methods appear ad hoc by the standards of an ideal innovation policy, they may actually be quite justified. In fact, research suggests that such opportunistic experimentation and improvisation may be reasonable, given the nature of these constraints.

Since the advent of widespread pollution concerns in the middle of the 20th Century, economists and political scientists have formulated increasingly rigorous methods to

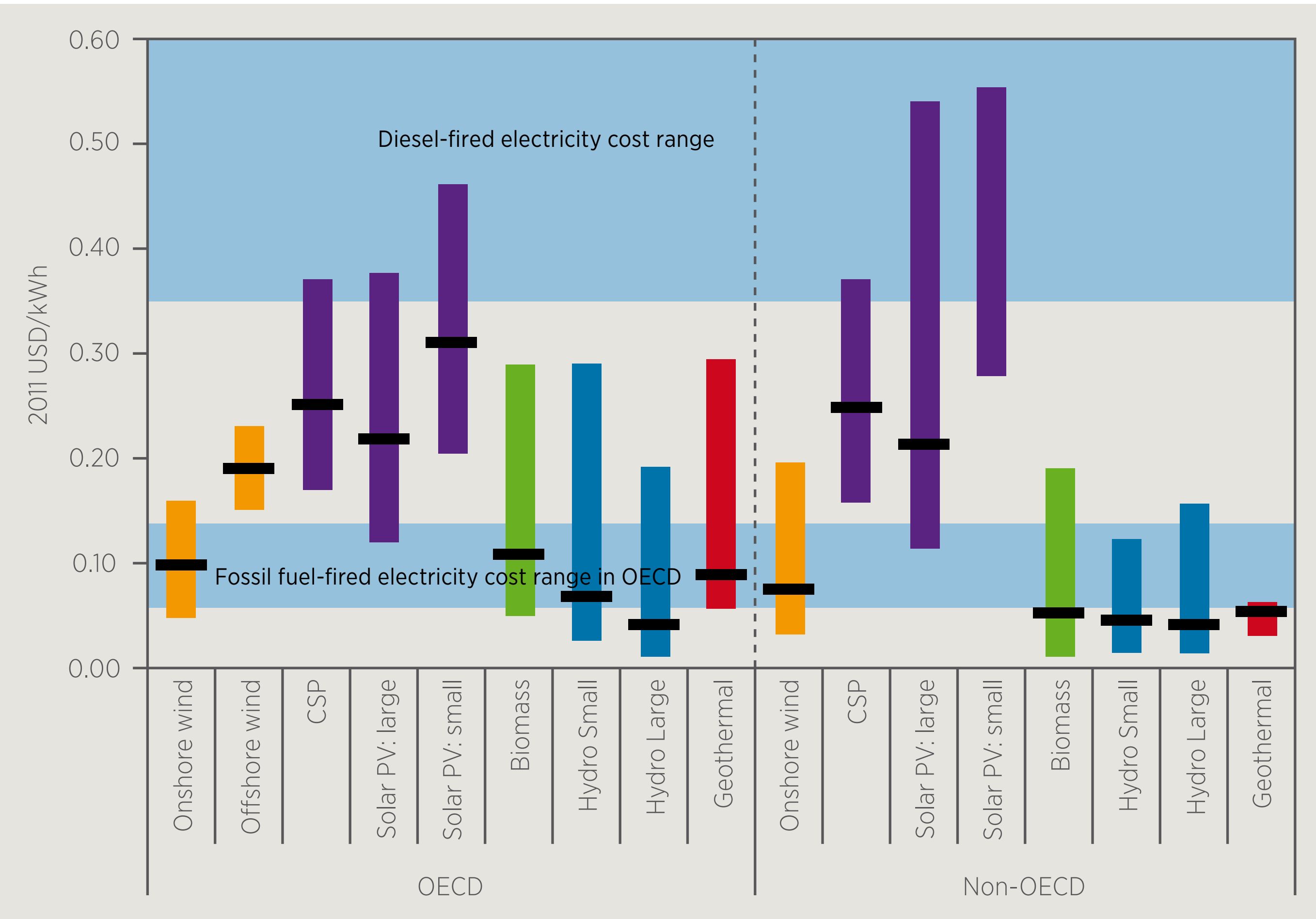

FIGURE 5: LCOE FOR DIFFERENT RENEWABLE ENERGY TECHNOLOGIES[12]

evaluate the effectiveness of policy instruments designed to achieve environmental goals. Much of this research focuses on the challenges of crafting optimal policy (in terms of social welfare) in markets where multiple constraints (political considerations, policy failures, or market failures) cannot be removed. In cases where there are many constraints of these types, even when one or two can be corrected at a given time, welfare is not necessarily improved. This is known as the "second-best" problem.[3] For example, in a world where all nations employ local content requirements for RET equipment, and one country considers unilaterally removing its local content requirements, strict economic analysis might deem such a policy desirable, i.e., welfare-enhancing. However, unilateral policy action amidst sustained local content requirements in other countries may in fact be welfare-reducing.

The energy innovation domain presents many signature examples of the second-best problem. Multiple exogenous constraints are at work, and it is unlikely that they would all be ameliorated simultaneously. Market failures associated with particulate pollution and carbon emissions are layered on top of market failures associated with the innovation and diffusion of new technologies.[13] Additionally, competing policy priorities (e.g., the estimated USD 409 billion in global annual fossil-fuel subsidies[14]) further constrain RET deployment and innovation. In the face of these and other constraints, the use of multiple, coordinated policy instruments is advisable if RET innovation is indeed a public policy goal.

3.2. Demand-side RET Policies and Innovation

In the field of RET innovation, the "second-best" critique is most relevant to the idea of a single demand-side policy instrument deployed in isolation, such as a carbon tax, an emissions trading system, or a renewable portfolio standard. Because the overarching constraints on innovation are multiple and varied, "second-best theory suggests that the elimination of one market failure – in a world with many market failures – may not be welfare-enhancing."[3] In such a world, multiple policy instruments, each designed to ameliorate specific constraints, are a reasonable choice.

Nonetheless, demand-side policies are increasingly common. At the end of 2011, 96 countries, more than half of them developing nations, had policy targets for renewable energy.[15] While demand-side policies have demonstrated the ability to accelerate RET deployment, the impacts of these same policies on innovation capacity are less clear. In Germany, the European Emissions Trading Scheme has had a mixed impact on innovation in the power generation technology sector, tending to promote innovation in fossil-fuel technologies.[16] With regard to emissions cap-and-trade policies, research indicates that innovation in emissions-control technologies for sulphur oxides (SO_x) and nitrogen oxides (NO_x) (as measured by patenting activity) actually declined under a cap-and-trade policy regime in the United States.[17]

With regard to quota systems, in the United States, the Energy Independence and Security Act of 2007 set annual fuel-blending requirements for second-generation (cellulosic) biofuel of 250 million gallons for 2011 and 500 million gallons for 2012. As of January 2012, little of this fuel could be found outside laboratories and workshops.[18] The readiness of the technology was not on par with the ambition of the mandate. In the power sector, an increasing body of research suggests that among the various forms of demand-pull policies, feed-in tariffs are among the most cost-effective[19][20][21] and the most likely to encourage local ownership of RET generation.[22] Emerging market countries, including Pakistan[23], Malaysia[24], Ecuador[25], and Uganda,[25] are increasingly turning to the feed-in tariff as the demand-side policy of choice. As feed-in tariff policies mature, and their impacts become more apparent, further research indicates that optimising specific design

3 Bennear, L. S., & Stavins, R. N. (2007). Second-best theory and the use of multiple policy instruments. Environmental and Resource Economics, 37(1), 111–129. doi:10.1007/s10640-007-9110-y. Bennear and Stavins describe the second-best problem as follows: "If a constraint exists within the general equilibrium system that prevents attainment of one Pareto optimal condition, then attainment of other Pareto optimal conditions is no longer necessarily desirable, i.e., welfare improving… The constraint may be a market failure, a policy failure, or a political constraint. For example, imagine a country that decides to reduce trade tariffs in a world where other countries utilise trade tariffs. A basic economic analysis would suggest that the decision to reduce trade tariffs by one country is welfare improving. However, given the existence of the exogenous constraint(s)—namely that other countries continue to use tariffs—this reduction in tariffs can actually be welfare reducing… Another way to frame the second-best problem is that if there are multiple constraints that prevent the attainment of multiple Pareto optimal conditions, the elimination of only one of the constraints does not necessarily lead to a welfare improvement… If the constraints are market failures, then second-best theory suggests that the elimination of one market failure, in a world with many market failures, may not be welfare enhancing. In fact, market failures can be *jointly ameliorating* (correction of one market failure ameliorates welfare losses from the other), *jointly reinforcing* (correction of one market failure exacerbates welfare losses from the other), or *neutral* (correction of one market failure does not affect the welfare losses from the other)…"

elements will help maximise feed-in tariff effectiveness, such as technology-specific price-setting and reductions in price, over time.[26]

In other contexts, too little ambition in demand-side policies can also be problematic. In Chile, analysts observed that while quotas for RET production have elicited some response from international firms, legislation has not proved aggressive enough to jump-start a robust domestic RET development industry.[27] The same analysts point to the fact that Chile is reconsidering its quota-based system in light of the limited effects of current demand-side policies.

Research on these various demand-side policy instruments suggests that while they are important to achieving near-term decarbonisation, their impact on breakthrough innovation is mainly via *learning effects* rather than direct innovation or the creation of indigenous innovation capacity.[28] Given the relatively low level of existing capacity to innovate at the technology frontier in low- and middle-income countries, we assume that deployment-related learning effects will be the primary pathway for growth of indigenous innovation capacity. Encouraging the creativity required to adapt established technologies to new markets in specific national contexts is an important task that, if properly leveraged, can deepen capacity for future innovation. Policy-makers can help realise this potential by crafting policy portfolios appropriately tailored to national energy development goals.

3.3. The Entrepreneurial Perspective

Another important consideration for effective RET innovation policy is responsiveness to the needs of innovators. While indications of sustained demand – a key feature of demand-side policies – are critical for entrepreneurial innovation, a wide range of other general factors may enhance the attractiveness of a particular nation or region. These include absolute market size and growth rates, availability of appropriately skilled labour, access to land and capital, adequate infrastructure, and transparent policy and governance. In some tightly integrated supply-chain industries, access to clusters of suppliers may also motivate entrepreneurs, although the effectiveness of cluster-based innovation policy has not been conclusively proved.[29]

Not all innovators have the same requirements within a given RET domain, such as residential solar PV installation). For example, multinational firms and local small enterprises may compete for PV installation market share in a particular region, but their innovation profiles will be typically quite distinct.

Analysis of the requirements of end-users, entrepreneurs and investors should inform innovation policy development. As discussed above, such requirements vary significantly between national contexts and specific technologies, and they change over time as technologies and markets evolve. Even in settings with very low per-capita income, RET entrepreneurship is likely to be a critical component for RET deployment. The International Finance Corporation estimates a global market size of USD 37 billion for energy services for low-income customers, representing a significant opportunity for adaptive innovation, given favorable policy and business climates.

A range of government policies significantly impact on the decision landscape of entrepreneurs and investors. As RET market size and growth rates are often influenced by national or regional energy policies, innovators and investors tend to consider current and future demand-side energy policy plans when evaluating investment options. Other key points of evaluation for entrepreneurs are also policy-dependent. Access to skilled workers, adequate infrastructure, intellectual property protection, labour law, and property rights are each interdependent with governmental policy regimes. Significant empirical research focuses on these interactions between the general policy environment, innovation, and economic growth.[4] This report does not examine these issues in depth, but it recognises that good governance, the rule of law, and investments in public goods (such as education and infrastructure) are just as important in supporting RET innovation as they are in promoting national economic development in general.

3.4. Towards Practical Guidelines for RET Innovation Policy

Practical guidelines for renewable energy innovation policy should recognise that the needs of RET entrepreneurs are highly diverse; that innovation and investment opportunities are highly dependent upon the policy landscape; that multiple innovation policies are often justified; and

4 See for example, Jaffe et al (2005); Freeman, C., Soete, L. The economics of industrial innovation. MIT. Cambridge. US. 1997; and Aghion, P., & Tirole, J. (1994). The Management of Innovation. The Quarterly Journal of Economics, 109(4), 1185–1209. doi:10.2307/2118360

that sustained policy commitment typically improves innovation outcomes. While the toolbox of RET innovation policy instruments has matured since the United Nations Conference on Environment and Development (UNCED or Rio Summit) 20 years ago, the practical application of policy measures is an ongoing challenge. Significant questions remain about how to design, sustain, evaluate, and if necessary, re-design innovation policy frameworks.

Furthermore, while the innovation policy research community began to direct more attention to the challenges facing emerging economies in the 1990s, it has only recently begun to focus on the unique case of RET innovation capacity in emerging economies. And, within this growing body of literature, the bulk of research tends to focus on "outlier" countries, those whose underlying characteristics are not widely shared by other emerging economies – especially China, Brazil, or India (which, with Russia, make up the BRIC countries). Emerging economies outside of this group – i.e., "non-BRIC" countries and "non-OECD" (Organisation for Economic Co-operation and Development) countries – represent a total population exceeding three billion people. This report sets forth an approach intended to be broadly useful to many countries, aiming to identify policy strategies that are particularly relevant to policy-makers outside of the BRIC and OECD regions.

While innovation is a common aspiration for many firms and countries, at a policy level innovation itself is typically a means to an end, such as economic growth, domestic security, international competitiveness, or poverty alleviation. Seen another way, few countries have marshalled a sustained, broadly shared national commitment to making a more efficient wind turbine or solar cell; but various countries have marshalled a commitment to supporting national wind-turbine manufacturing as a source of international competitiveness. Innovation policy-makers who recognise that innovation is rarely (if ever) an end in itself will be free to craft policy that is more tightly linked to fundamental drivers of durable policy regimes.

In light of these observations, we propose that successful innovation policy regimes meet two broad strategic criteria:

1) They promote sustained multi-stakeholder engagement around an achievable, shared vision; and

2) They appropriately position a country or region to anticipate and benefit from renewable energy technology flows.

These criteria reflect two practical features of RET innovation policy development. The first is that because innovation arises from a mix of social, financial, and technical factors, responsibility for innovation policy is distributed across many stakeholders within the public sector. Thus, success will be promoted insofar as innovation policy discussions are integrated into existing macro-level policy goals, as the latter will provide a level of stability and multi-stakeholder engagement that might otherwise be lacking. The second is that innovation policy succeeds by cultivating *innovation capacity*. This growth can be measured by the ability of a nation or region to anticipate and benefit from flows of technology, accumulate stocks of knowledge and social capital, "learn how to learn," and shift the rates of productivity and technological accumulation.[5]

To help meet these criteria, RET innovation policy formation can be strategically situated within the context of policy planning for long-range energy development goals. Achieving this alignment promotes engagement with appropriate stakeholders, supports the formation of achievable, shared objectives, and positions a nation or a region to benefit from specific RET technology flows. Furthermore, this alignment supports the design and implementation of strategic policy portfolios targeting the enhancement of innovation capacity. Such portfolios may span demand-side measures and knowledge and technology transfer measures, and may be tailored to maximise impact, given the nature of specific economic, policy, and infrastructure constraints. Section 4 discusses five common long-range energy development goals and their strategic value in informing RET innovation policy regimes.

5 The framing of these concepts owes much to Narula, R. (2004). "Understanding Absorptive Capacities is an "Innovation Systems" Context: Consequences for Economic and Employment Growth." Danish Research Unit For Industrial Dynamics Working Paper No 04-02. December 2003.

4. RENEWABLE ENERGY INNOVATION IN THE CONTEXT OF ENERGY DEVELOPMENT GOALS

Given the specific national and regional ecosystems in which RET deployment is carried out and innovation policies are formed, analytical approaches that support context-specific policies promise to support more coherent strategies and accelerate the speed and scale of RET deployment. While the processes (and end results) will look significantly different across various national contexts, the strategic approach outlined in this section aims to be accessible and relevant to policy-makers in many settings.

Energy development policy impacts on, and is impacted on, by most other critical public policy issues, and will remain an enduring point of concern at both national and sub-national levels. Energy development is interrelated with economic growth, sustainable development, urbanisation, education, women's rights, disease prevention, agricultural development, and many other concerns.[6] In policy dialogues around energy development, various themes or goals commonly recur. This report identifies and discusses six of these (although there are certainly other motivating forces that shape energy policy development). The energy development goals of interest are:

1. *Energy Security*, focusing on reducing dependence on vulnerable energy supplies.

2. *Energy Access*, focusing on reducing energy poverty and expanding access to secure, reliable, and low-cost energy.

3. *Energy Cost*, focusing on reducing exposure to persistently costly energy services.

4. *International Competitiveness*, focusing on achieving greater competitiveness in international energy markets.

5. *Modernisation*, focusing on modernising national energy systems.

6. *GHG emissions reduction*, focusing on reducing the GHG and impacts on environment.

These goals are each capable of garnering broadly shared support across a wide range of settings. They are not mutually exclusive – indeed in many countries they are commonly found in combination. The following sections of this report include a description of the general characteristics of each goal, historical examples, likely technology flows and stakeholders, and list the key opportunities and challenges of implementing a harmonised renewable energy innovation policy portfolio.

4.1. Energy Security

Energy security is a durable theme in countries supplied by uncertain sources of energy, whether due to geography, politics, or both. Vulnerability to energy shocks is a key feature of such countries, and achieving a degree of insulation from these shocks will be a persistent motivating force. Consequently, these countries will probably focus on reducing the importance of the vulnerable energy source, typically imported natural gas, coal, or petroleum.

6 These and others are discussed in UN-Energy (2005). The Energy Challenge for Achieving the Millennium Development Goals. http://www.un-energy.org/sites/default/files/share/une/un-enrg_paper.pdf Accessed 27 July 2012.

Examples
Brazil's exposure to the second oil shock of 1979[7] mobilised sufficient political will to embark on a national effort to develop domestic ethanol sources.[30] Decades of innovation resulted in significant technical and commercial advances. Consequently, Brazil was for many years the largest exporter of ethanol in the world, and was overtaken only recently by the United States in 2011.[31] In 2004 Chile faced shortages of natural gas from its main supplier, Argentina, leading to higher expenditures on conventional replacements (diesel).[32] One of the main remedies – the construction of a USD 1.1 billion liquefied natural gas (LNG) terminal[33] – illustrates the point that policy-makers and project developers can opt to pursue many pathways towards reduced energy dependence, e.g., geographic diversification of conventional fuel sources.

Israel, which faces significant vulnerability to its coal, natural gas, and diesel supplies, established a national mandate in 1980 for solar hot water heating, and consequently has the second-largest per-capita use of solar water heating after Cyprus.[34] Many Israeli solar water heat companies are leaders in their field, and have expanded into other types of solar innovation. Ukraine, which faces significant vulnerability to Russian natural gas supplies, has recently also made moves towards greater energy security through a feed-in tariff for wind and investments in pumped-storage hydroelectric generation.[35]

Technology Flows, Innovation Activities, and Innovation Capacity
Progress towards energy security can be achieved through various parallel pathways, including increased energy efficiency, greater deployment of RETs, and diversification of conventional fuel supply routes (similar to the Chilean LNG example above). In light of this competition between pathways, commercially-ready RETs such as biomass generation, wind power, solar power, and large- or small-scale hydropower, are the more likely candidates for deployment. Correspondingly, later-stage innovation activities, specifically *commercial scale-up* and *adaptation*, will be particularly relevant in the process of working towards national energy goals. Capacities to support deployment of these technologies will probably include utility-scale RET project development and finance, transmission planning and advanced grid operation, and logistical support activities. Policies to support these capacities are discussed in the table at the end of this section.

Challenges
Reducing vulnerability to supply shocks requires significant displacement of conventional fuel demand, and so the scale of RET deployment is important in these contexts. Depending upon the domestic balance sheet and financial sector, international investment may be particularly useful in achieving sufficient scale, and so it is important to cultivate a supportive investment climate. In cases where vulnerable fuel sources are used for baseload electricity generation, variable RETs (such as wind and solar) will only partially ameliorate dependency on conventional fuels. To the extent that energy end-uses are vulnerable – e.g., petroleum for transportation or natural gas in hot water heating – the problem of displacing conventional fuels may be uniquely complex since end-users must purchase new equipment in order to use alternative renewable fuels. Additionally, depending on the frequency of price shocks, political will for a sustained RET deployment and innovation effort may or may not be easily achieved.

Opportunities
Vulnerability to energy insecurity can provide periodic groundswells of support for energy diversification,[8] facilitating multi-stakeholder engagement and exploration of various options. Reducing dependence on petroleum for transportation presents an opportunity to promote various alternative transportation technologies, such as electric vehicles, biofuel vehicles, or hydrogen fuel-cell vehicles. Reducing dependence on natural gas, petroleum, or coal for electricity generation is likely to promote an interest in RET project development alongside large-scale energy efficiency and conventional fuel source diversification. Each of these technology flows can support significant corresponding flows in knowledge and technology, which will be the basis for domestic entrepreneurship and international collaboration.

Critical Steps
Innovation under an energy security frame can be promoted by inviting collaboration between domestic and international firms in pursuit of long-term energy development targets. The conditions for successful partnerships and technology transfer through private sector relationships

7 The term "second oil shock" refers to the oil price increases after the Iranian revolution of 1979. The first oil shock was in October 1973, when members of the Organisation of Arab Petroleum Exporting Countries proclaimed an oil embargo following the Arab–Israeli War in that year.
8 See for example EU responses to natural gas supply crises of the 2000's in Ratner et al (2012). Ratner, M. Belkin, P. Nichol, J. Woehrel, S. Europe's Energy Security: Options and Challenges to Natural Gas Supply Diversification. Congressional Research Service. 13 March 2012. http://www.fas.org/sgp/crs/row/R42405.pdf Accessed 17 July 2012.

Table 2: Examples of innovation policy tools in support of energy security

Function	Example Policy Tools
Creating and Sharing New Knowledge	Support for studies to quantify value of energy security; High-resolution RET resource assessments; Grid modelling efforts to estimate system performance under varying penetrations of RETs.
Building Competence and Human Capital	Subsidies and incentives for education and training in the fields of power sector engineering, project development, finance, engineering, and construction.
Knowledge Diffusion / Creating Collaborative Networks	Joining or initiating international cooperation with other nations seeking energy security; Supporting industry consortia to identify gaps and opportunities regarding energy use and energy efficiency.
Developing Infrastructure	Facilitating large-scale RET deployment through investment in appropriate grid infrastructure, roads, rail, and ports.
Providing Finance	Project finance loan guarantees; "Green" banks or some form of revolving funds; Public bonding support for infrastructure.
Establishing Governance and the Regulatory Environment	Robust intellectual property protection and legal recourse for joint ventures; Policies to improve investment climate; Specific and credible energy efficiency and renewable energy targets; Utility-scale interconnection standards.
Creating Markets	Feed-in tariffs; Renewable Portfolio Standards; Government/public procurement.

include minimising transaction costs, strengthening collaborative mechanisms, and cultivating trust and credibility in joint ventures and Public-Private Partnerships.[36] In support of these enabling conditions, policy priorities should focus on reducing bureaucratic barriers to foreign direct investment (FDI), enhancing legal protections for parties to joint ventures, and providing adequate contractual assurances to project stakeholders. More broadly, policy-makers might consider targeted training and coordination support, e.g., technical training for locally hired staff or sponsored trade missions to advance new partnerships. Specifying the likely technology flows, drawing upon high-quality renewable energy resource assessments, will also assist in structuring brokerage activities with domestic stakeholders. These and other specific policy options are collected in Table 2.

4.2. Energy Access

Nations with high levels of poverty and low levels of energy access are likely to enjoy sustained support from the international community for effective poverty alleviation. RET deployment and poverty alleviation can be mutually reinforcing, as energy access can reduce per unit energy costs and improve the conditions for economic growth.[37] Energy access as a long-term energy development goal strongly shapes RET innovation avenues and the requisite innovation capacities.

Examples

Significant advances in energy access have been achieved through various distributed energy system configurations, ranging from fully off-grid generation to neighborhood-level mini-grids to grid-based electrification.[38] At the level of the individual or family, sales of "solar home systems," comprising solar PV panels integrated with lighting, have grown quite rapidly in India, Sri Lanka, China, Tanzania, Bangladesh, and elsewhere.[39] These markets are highly sensitive to the availability of appropriate financing options, such as the 20% up-front/three-year financing package offered by the not-for-profit Bangladesh renewable energy company Grameen Shakti.[40]

At the village level, mini-utilities have achieved success in certain settings, often delivering electricity through a mix of conventional (i.e., diesel) generation and renewable sources such as small hydro, PV, or biomass facilities.[41] The use of renewable technologies has become increasingly common in south and east Asia. India and China have reportedly reached 4 million and 40 million biogas systems, respectively, by the end of 2011,[42] and rice husk power plants in India now serve at least 50 000 citizens. [43] China has deployed more than 45 000 units of small hydropower (< 10MW) for rural applications.[44]

Commercial or quasi-commercial grid extension efforts are underway in Latin America (e.g., CONDENSA in Colombia, CEMAR in Brazil), Africa (e.g., COMASEL in Senegal, One-PPP in Morocco), India (e.g., North Delhi Power Limited, Ahmedabad Electricity Company). Publically funded grid extension efforts are either underway, or completed, in South Africa, Vietnam, and China.[45]

Technology Flows, Innovation Activities, and Innovation Capacity

Depending upon the composition and coincidence of electricity end-uses, energy access can typically be expanded at least cost through neighborhood-level systems involving a minimum of 1 000 customers. In contexts where this level of community grid modernisation is feasible, design and deployment of RET will not be the only important technology flow; the associated mini-grid engineering, construction, and operation activities will present significant opportunities for local capacity-building and innovation.

The proportion of off-grid, mini-grid, and grid-connected RET deployment will depend heavily on local context. While modern grid construction may be a long-term goal, off-grid and micro-grid operation may be the predominant forms of RET deployment in the near term. Increasingly affordable own-generation systems – including solar home systems, small hydropower systems, small biogasifiers, or modern devices for direct energy use, such as advanced cook stoves – may represent the dominant technology flow in these contexts. Analysts estimate that approximately 58 million households globally pay USD 8.50 or more per month for energy services, a level at which basic home energy storage technologies may also be economically competitive.[46]

In some settings, extending existing grids to low-income customers is another viable pathway for expanding energy access. Technology flows via this methodology may centre more on grid equipment and operational efficiencies such as prepayment systems, customisable billing, and finance systems designed for low-income customers. Extending existing grids to those on very low incomes typically delivers a low return on investment, and so few fully unsubsidised models exist.

Given the priority given to commercially available technology, the innovation capacity growth generated by the pursuit of energy access derives mainly from the learning effects of RET adaptation (both business model and technical) across off-grid, mini-grid, and grid-expansion settings. Capacities to support this pattern of technology deployment include power system engineering and maintenance, energy business entrepreneurship, effective stewardship of donor funds, and non-traditional financing structures. Clarifying the financial costs and business models available to potential entrepreneurs can also help.

Challenges

Key challenges facing RET deployment include overcoming established habits of fossil- and biomass-based energy use; overcoming high transaction costs of rural RET systems; meeting the expectations of end-users; addressing the limited buying power of end-users; meeting rigorous requirements for system durability and ease of maintenance; addressing issues of education and training; and establishing functioning, profitable business models for deployment.

Resource assessment data may also be difficult to assemble in remote regions. Such difficulties are most acute with hydrological and biomass resources, which are variable and depend on climatic conditions (which may be in flux) and competition for land use.

Many contexts with low energy access also have low to moderate levels of educational attainment, which can limit capacity for technology absorption. Similarly, foreign direct investment in support of energy development may be slowed by barriers to investment. Finally, where energy access portfolio strategies aim to encourage the local manufacture of energy equipment (e.g., turbines, gasifiers, integrated solar home systems), low levels of manufacturing capacity may present a short-term barrier to gaining maximum benefit from technology flows.

Opportunities

As technology flows in these contexts tend towards smaller systems rather than utility-scale RET development, key opportunities include a central role for small- and medium-enterprises and the possibility of partnerships with existing business development and micro-finance initiatives.

In many settings RET system configuration will be culture-specific. While this may limit international collaboration to some extent, it also increases the success rate of local entrepreneurs in creating novel business models, since outside firms may be hesitant to enter the market. Consequently, there are strong opportunities to leverage existing

9 Diversity of electricity demand reduces the coincidence of load, allowing for more efficient allocation of generation capacity. Systems involving 1,000 customers can operate using a little as 10% of the capacity of a system in which all customers generate their own electricity. See Strbac, G., N. Jenkins, and T. Green. 2006. Future Network Technologies - Report to DTI. http://tna.europarchive.org/20081112122150/http://www.berr.gov.uk/files/file31649.pdf Accessed 15 November 2012.

Table 3: Examples of innovation policy tools in support of energy access

Function	Example Policy Tools
Creating and Sharing New Knowledge	High-resolution RET resource assessments in areas with low energy access; Studies to quantify market size of low- and middle-income consumers; Opportunity and gap analysis of RET deployment in off-grid settings; Analysis of future grid modernisation pathways.
Building Competence and Human Capital	Subsidies and incentives for education and training in the fields of off-grid system design and equipment maintenance, micro-grid design and engineering, power system planning; entrepreneurship, marketing, micro-finance.
Knowledge Diffusion / Creating Collaborative Networks	Joining or initiating international cooperation aimed at expanding energy access; Supporting community groups and entrepreneurs working towards RET deployment; Supporting micro-finance networks.
Developing Infrastructure	Facilitating grid development in high-priority areas; Improving telecommunications coverage to enable novel smart grid applications.
Providing Finance	Support for energy technology micro-finance models; Removing barriers to both traditional and novel finance pathways.
Establishing Governance and the Regulatory Environment	Setting specific energy access targets; Establishing micro-grid interconnection standards, Bolstering property rights for low-income citizens; Removing barriers to novel business models, such as solar system leasing.
Creating Markets	Feed-in tariffs extending to micro-grid operators and low-income citizens; Public procurement of RET systems in government-subsidised housing.

efforts to reduce poverty to create pathways for business creation in the field of RET deployment.

Critical Steps

Critical steps in adopting this portfolio include tightly integrating RET deployment into existing efforts to promote poverty alleviation and economic growth; providing adequate access to high-quality technical and business training programmes to support small- and medium-enterprise development; providing finance (and/or micro-finance) for business development, working capital, and fixed capital expenditures; and establishing standards for system performance to ensure quality and reliability. Further examples are provided in Table 3.

4.3. Energy Cost

Many countries face chronic exposure to the problem of persistently high-price energy sources. While this challenge is similar to the one described above regarding energy security, this section focuses specifically on contexts marked by geographic isolation or remoteness. In addition to high costs for fossil fuels, such locations also face unique barriers such as relatively small market potential and high costs for ancillary materials and personnel required to service energy systems. Consequently, they are likely to consider a wide range of solutions spanning grid-connected and distributed RETs, energy efficiency, grid modernisation and alternative transportation, since improvements in any of these areas could help reduce fossil fuel use.

Examples

Remote islands are the signature example of this energy development goal. A select group of island nations has already developed unique pathways to reduce dependence on fossil fuels, and a wide range of island nations is currently aiming to follow their example. Iceland was an early leader, gradually replacing its oil-fueled district heating with geothermal systems between 1940 and 1975.[47] Today, Iceland generates 83% of its primary energy and 100% of its electricity from renewable sources.[48] Cyprus reduced its electrical generation load by developing a flourishing solar water heating industry in the 1980s.[49] Today, as fossil-fuel prices rise, dozens of island nations and territories spanning the Pacific, Atlantic, and Indian Ocean basins are organising efforts to reduce fossil-fuel dependency.[50]

Technology Flows, Innovation Activities, and Innovation Capacity

Similar to energy access contexts, energy costs settings may favour off-grid and mini-grid RET system configurations. Where diesel electricity generation typically prevails, hybrid systems (RET + diesel) may play a uniquely important role. Furthermore, islands tend to face high costs for solid waste disposal, making waste-to-energy systems more common.[51] Finally, given the chronic costliness of energy, battery or chemical storage options that might not be viable elsewhere can find a role in these settings.

Grid modernisation is usually an important consideration in island settings, as existing grids may not be designed to accommodate sizeable increases in variable generation. In cases where solar and wind resources are abundant, balancing resource variability with power load output will be a technical priority at the system level, and ensuring voltage stability will be a priority at the level of individual distribution networks.[52] At the system level, additional flexibility resources, such as modern diesel generators or demand response, may be required to accommodate higher levels of RET deployment.

Alternative transportation technology flows are also common in high-cost settings. As fossil fuels in remote settings tend to be used for electricity and heating, as well as transportation, their use in transportation assumes a greater systemic importance. Various technological alternatives exist, including, but not limited to, electrification, biofuels, and hydrogen-powered vehicles. Achieving significant penetration of alternative transportation (both land and marine) will be an important task for innovative capacity.

In light of these activities, it is often necessary to significantly adapt commercially available technologies in island settings, and a certain degree of technology demonstration may also be needed, for example in energy storage, novel micro-grid configurations, biofuels production, or typhoon-resistant wind turbines.

Challenges

Due to their geographic isolation, regions with high energy costs also tend to have relative disadvantages in existing innovation capacity, as reflected in low levels of educational attainment, skilled labour, or high-tech employment. Furthermore, such regions are typically remote, making deployed systems more difficult to install, maintain and insure. For these reasons, potential investors from outside the region may view investments with a degree of caution. Similarly, even as energy costs stabilise, or even decline, with the integration of RET and energy-efficiency solutions, remote settings may face persistent disadvantages in accumulating the robust social networks that underpin much indigenous innovation capacity.

Opportunities

Countries with high energy costs face significant challenges, but they may also benefit from certain economic, policy and technology advantages. The overarching opportunity is economic – a wider range of solutions will be financially viable in high-cost energy settings. As a result, the market landscape for entrepreneurship and innovation is inherently broader. A second opportunity is the relative ease of garnering political support in settings where energy costs significantly hold back economic activity. High energy costs promote political will, at least at a high level of government. A third opportunity lies in the relaxation of some of the policy development constraints common in larger nations. In remote settings, fewer policy options may be competing for constrained budgets, and implementing and evaluating policy effectiveness may be inherently easier in smaller nations than in larger ones.

Critical Steps

The critical steps in high-cost settings pertain less to marshalling political will then to positioning it to achieve maximum benefits from diverse technology flows. RET deployment, energy efficiency, and transportation can all be expected to produce important technology flows that represent areas for innovation capacity growth. Given the distinct nature of each of these technology domains, positioning political will to leverage each flow is a critical challenge.

A related critical step is a holistic assessment of the whole energy sector from supply to grid and end-use. These steps are commonly taken in the development of a national or regional energy roadmap, a growing area of practice.[10] Such assessments can assist in prioritising energy policies and in convening multi-stakeholder networks comprising firms, citizens, thought leaders, and policy-makers. Promoting partnerships between local and outside firms can help accelerate knowledge flows, and providing incentives for local hiring can deepen the impact of foreign direct investment.

Finally, a key area of policy focus will be development of human capital. A threshold level of education – potentially measured by secondary and tertiary educational attainment – is critical in order to absorb the various technology flows that may emerge in these settings. Aligning educational policy, and potentially immigration policy, with these goals will help advance innovation capacity growth.

10 The growing role of energy roadmaps is detailed in Ochs and Makhijani (2012). Ochs, A., Makhijani, S., Worldwatch Report #187: Sustainable Energy Roadmaps: Guiding the Global Shift to Domestic Renewables. March 2012.

Table 4: Examples of innovation policy tools in support of reducing energy cost

Function	Example Policy Tools
Creating and Sharing New Knowledge	High-resolution RET resource assessments; Energy road-mapping and associated system analyses; Grid capacity studies.
Building Competence and Human Capital	Subsidies and incentives for education and training in the fields of off-grid system design and RET equipment maintenance, micro-grid design and engineering, power system planning; Biofuels production, energy efficiency, entrepreneurship, marketing, micro-finance.
Knowledge Diffusion / Creating Collaborative Networks	Initiating or joining international cooperation; Supporting community groups working towards energy access; Supporting micro-finance networks.
Developing Infrastructure	Grid modernisation; Vehicle electrification infrastructure; Biomass logistics and processing infrastructure.
Providing Finance	Project finance loan guarantees; Collaboration with international bodies to support financing and insurance of RET systems; Support for energy technology micro-finance models; Removing barriers to novel finance pathways.
Establishing Governance and the Regulatory Environment	Establishing distributed generation and micro-grid interconnection standards; Designating RET project development areas; Setting energy efficiency standards; Removing barriers to novel business models, such as energy performance contracting or solar system leasing.
Creating Markets	Renewable Portfolio Standards; Feed-in tariffs; Energy Efficiency Obligations; Public procurement of RET systems in government buildings; Incentives for alternative fuel vehicles and energy efficiency.

4.4. International Competitiveness

A number of countries possess skills and capabilities developed through internal market development, and aim to leverage these assets in pursuit of external growth opportunities. In these settings there is usually broadly shared agreement about the importance of advancing economic competitiveness on the international stage. The presence of an overarching goal of competitiveness can strongly shape RET technology opportunities, and should inform RET innovation policy in important ways.

Examples

This pathway has been most recently illustrated by Chinese wind turbine manufacturers, who have transitioned from mainly domestic activity to a greater focus on international export.[53][54] Similarly, Chinese PV manufacturers have leveraged extant manufacturing and labour advantages to become a dominant force in the international PV market. Between 1975 and today, Brazil leveraged domestic demand and agricultural expertise to become an international export leader in ethanol.[55] Another example is Germany, which between 2000 and 2011 leveraged growing domestic demand and existing manufacturing expertise to become a global export leader in solar PV panels and manufacturing systems.[11] In all of these cases, general policies to promote international competitiveness (e.g., credit guarantees, trade missions, participation in multilateral trade bodies such as the World Trade Organization, incentives for international business training) shaped the opportunity landscape for RET innovation.

Various countries outside of the OECD and BRIC contexts possess a threshold level of experience in a given technology that could be leveraged in global markets. For example, the Philippines (see Text Box 1) has developed significant national capacity in geothermal energy deployment and may find opportunities for international applications of its project management and resource assessment expertise. Vietnamese entrepreneurs are beginning to produce low-cost light-emitting diode (LED) bulbs and electric cars, aiming to achieve sufficient domestic demand in order to eventually tap into international markets.[56]

11 These three signature examples of a competitiveness focus are useful for illustrative purposes, but the underlying characteristics of China, Brazil, and Germany are difficult to emulate.

Text Box 1. Case Study: Geothermal Innovation Capacity in the Philippines

The Philippine Energy Development Corporation (EDC) is the second largest generator of geothermal capacity in the world, managing the development and operation of >1.0 GW geothermal projects across various islands of the Philippines. While working in close cooperation on exploration and technology with multinational companies such as Ormat and Chevron, the EDC has accrued significant exploration, project development, and facility management experience that represents a stock of innovation capacity for expansion to external markets.

Candidate policies to leverage such innovation capacities are detailed in Table 5.

Technology Flows, Innovation Activities, and Innovation Capacity

In contrast to the energy development goals described above, technology flows under an international competitiveness strategy are likely more to be sensitive to international market trends than to domestic deployment patterns. Additionally, achieving international competitiveness may involve the establishment of joint-venture partnerships with firms from other countries, leading to technology flows that will be strongly shaped by the terms of the joint ventures. The innovation activities and capacities of existing firms may play a uniquely important role in this context.

Outward focus on global RET markets might take the form of a targeted niche role in a supply chain (e.g., linking existing agricultural expertise to produce biofuel feedstocks for regional markets), original equipment manufacturing at a global scale (such as the global manufacturing footprint of India's Suzlon),[57] or a targeted role in ancillary services such as system modeling, project development, or renewable resource assessment. In this sense, the technology flows are significantly more diverse and dynamic under the international competitiveness rubric.

Consequently, while innovation activities in pursuit of international competitiveness commonly revolve around commercially mature technologies, opportunities to participate in *commercial scale-up* and *technology venturing* will likely present themselves as well. Innovations at the earlier stages of technological maturity typically face greater prospects for success across multiple international markets than within any single market alone.

Challenges

Broadly speaking, the challenges of this portfolio revolve around effectively tracking and engaging with international market trends in support of expanding domestic innovative capacity. International activities in their own right may be difficult; significant language and business barriers may be in place, for example. Identifying and implementing appropriate joint-venture opportunities may be challenging. There are also significant challenges in competing with established firms in the international marketplace, marketing domestic products to global firms, or both.

Absorbing the knowledge and technology flows from international partnerships is not a trivial matter. Educational attainment is important in this regard, as knowledge spillovers from joint ventures depend critically upon adequate levels of technical and business expertise. At a policy level, this problem poses challenges in balancing the maximum transfer of knowledge and technology with robust protection for the intellectual property rights required by many bilateral and multilateral trade regimes.

Opportunities

With multi-stakeholder engagement, a key opportunity lies in making the relatively straightforward case that RET innovation policy supports national or regional goals to increase international competitiveness. Countries engaged in crafting policy to enhance competitiveness likely feature relatively well-established domestic networks of industrial and policy stakeholders. These stakeholders would be likely candidates to support RET innovation.

When positioning to absorb technology flows, effective joint-venture brokerage is key to this area of capacity building, as significant mismatches will inhibit both knowledge flows and business success. As with all innovation policy portfolios, educational policies to increase secondary and tertiary enrollment will generally accelerate adaptation-related learning effects as foreign firms form partnerships with domestic ones. Finally, there are opportunities to leverage networks of international institutions to assist in the brokerage of joint venture arrangements.

Critical Steps

Critical steps to implementing this portfolio include convening various policy stakeholders to promote integration of land, labour, grid, trade, education, and intellectual property rights regulation. Additionally, promoting opportunities to global firms is a key step, which may include providing credible and detailed renewable resource and grid data; performing timely assessments to match domestic firm capabilities to international market growth trends; identifying joint venture partners as necessary to facilitate entry into external markets; incentivising external growth opportunities; and establishing programmes that balance technology transfer goals with intellectual property rights protection.

Many countries aiming for international RET competitiveness possess a reasonably well-established manufacturing base and/or domestic renewable energy generation base, and a corresponding level of extant innovation capacity. These assets should be strategically leveraged through international partnerships, either domestically or abroad, to advance indigenous technical and business expertise.

4.5. Modernisation

Many countries have articulated ambitious visions for economic growth and industrial modernisation, and these policy goals can support RET deployment and the cultivation of indigenous RET innovation capacity. The country or region that might consider a modernisation innovation policy portfolio expects its electricity demand to grow rapidly, mainly through new commercial and industrial demand but also through demand from consumers with growing incomes; has enough renewable resources to support a significant share of domestic generation; has a large and growing middle class and so expects to see increases in residential electricity use and purchasing power; has significant established access to fossil-fuel resources and relatively low electricity prices; and has a moderate degree of RET knowledge, either tacit or codified.

Examples

Historically, Japan is a prime example of using a relatively new technology as a significant component in its overall industrial modernisation.[58] More recently, Chinese innovation capacity in the wind technology sector grew significantly between 2000 and 2012, bolstered by large government procurement of wind energy, a strategic series of policies designed to invite foreign companies to partner with Chinese firms, and subsequently a series of policies to transition to autonomous firm-level innovation. The policy strategies underlying this transition from "imitative" to "cooperative" and finally to "indigenous" innovation[59] are somewhat unique to China, but they present a useful case study of leveraging grid modernisation to promote innovation capacity.

Table 5: Examples of innovation policy tools in support of international competitiveness

Function	Example Policy Tools
Creating and Sharing New Knowledge	Detailed and regular international market and supply chain studies; Detailed analysis of domestic industrial and service capabilities.
Building Competence and Human Capital	Subsidies and incentives for education and training in international business, foreign languages.
Knowledge Diffusion / Creating Collaborative Networks	Brokering international joint ventures; Convening international conferences in-country to showcase indigenous capabilities; Supporting trade missions to markets of interest; Participation in multilateral trade bodies.
Developing Infrastructure	Less critical in this policy setting.
Providing Finance	Credit guarantees or other instruments to improve creditworthiness of domestic firms participating in joint ventures.
Establishing Governance and the Regulatory Environment	Favorable intellectual property protection and legal infrastructure to support joint ventures or other forms of international collaboration.
Creating Markets	Less critical in this policy setting.

Technology Flows, Innovation Activities, and Innovation Capacity

Similar to the energy security strategy, the modernisation goal may privilege rapid and large-scale development of RET generation capacity.[12] As such, commercially-mature technologies are likely to figure prominently in RET flows. Correspondingly, investments in grid infrastructure and enhancements to grid operations are likely to receive attention as the mix of the different types of power generation – the generation fleet – is involved.

Any available domestic renewable resources are also likely to strongly influence technology flows. When the priority is rapid growth in generation capacity, resource-rich areas are likely to be tapped first, whether they have wind, solar, hydro, geothermal, or some other resource. Here, resource assessment and prospecting will be an important enabler of RET deployment, as will effective project development and finance. Policy-making will play a key role in promoting enhancements to these capacities.

Challenges

Key challenges of aligning RET innovation policy to modernisation goals include attracting buy-ins from utilities and grid operators, and meeting the power quality expectations of industrial energy consumers. The challenge lies in demonstrating that RETs are a credible and manageable option for large-scale power generation. Existing preferences for fossil-based alternatives will also challenge RET innovation in high-growth settings. (For an example of this in practice, see Text Box 2).

Depending upon contextual factors, countries may also struggle to offer a market size or growth rate large enough to entice private firms and foreign direct investment. Finally, ensuring that the maximum possible amount of knowledge and technology transfer spills over from RET project development to domestic firms is a primary challenge for this strategy.

Text Box 2. Case Study: Parallel Visions of Modernisation in Indonesia

In 2007, Indonesia set an ambitious target – 17% of renewables in its energy mix by 2025. Then, in 2011, the country released an "economic master plan" with a target of becoming one of the world's 10 largest economies by gross domestic product (GDP) by 2025. After decades of intense industrialisation in western Indonesia (centered on the island of Java), the master plan is now looking eastward to islands with lower levels of economic activity, infrastructure, and electricity demand. Jon Respati, director of the Indonesian Renewable Energy Society's Solar Energy Center, welcomes this eastward vision, especially for the opportunities it would provide to forge a new path for Indonesia's economy. He sees the possibility of a clean energy industrialisation model, in which Indonesia "moves east" using geothermal, hydropower, and domestic natural gas as baseload power and large shares (approximately 20%) of solar energy to drive a low-carbon, low-cost economic boom. In the process, Indonesia could become a global leader in clean energy innovation and development, according to Respati.

However, in a country with ample coal and gas resources, the allure of rapid industrialisation using tried-and-tested fossil energy sources is strong, so justifying a significant role for RETs will be a key challenge. Notably, the master plan does not fully adopt a clean energy vision, instead focusing on support for manufacturing, agriculture, fisheries, mining, tourism, telecommunications, energy, and industrial zones. Much of this economic activity may depend heavily on fossil fuels.

The gap between these two visions for Indonesia – one of a clean-energy leader and the other of a rapidly industrialising powerhouse – highlights the tensions between renewable energy and national economic policy. If concerns about the reliability, cost or speed of RET deployment linger, when the time comes to ensure rapid economic growth, the "go-to" energy sources may remain coal, gas, and diesel.

12 While this development pattern is driven by displacement of existing generation capacity in the energy security setting, in the modernisation setting it is driven by rapid growth in demand. These drivers pose distinct opportunities and challenges to policymakers.

Opportunities
Key opportunities include rapidly growing energy demand, justifying the rapid construction of new capacity, which in turn bolsters policy support for RETs. The opportunity to link RET deployment to this rapid demand growth imperative is unique to this portfolio. Consequently, the opportunity to establish learning transfer mechanisms via the construction of new RET projects is critical to generating potential technology and knowledge spillovers.

Foreign direct investment may play a key role in energy modernisation. The foreign direct investment climate is typically enhanced by lowering non-cost barriers to investment, including siting, permitting, grid-connection, and other cost-of-doing-business factors. With such policies in place to promote entry for international firms, policy-makers can position industrial policies to benefit from resulting technology flows. (See Text Box 3).

Critical Steps
Critical steps include assessing and articulating the role of RET generation in national visions for industrialisation; establishing policy targets to drive large-scale RET deployment; and supporting innovation capacity growth through learning effects of RET project development and grid-integration. Policy targets and associated demand-pull efforts would prioritise openness to international investment, and would support the formation of working partnerships between grid system operators, utilities, RET developers, and financial institutions to accelerate the deployment of large-scale RET projects.

Text Box 3. Case Study: Chile's Modernisation Policy Portfolio

Observers in Chile report that the general RET innovation environment has improved due to a range of policy actions: the creation of instruments of direct support for RET project investment (e.g., government loans and grants for feasibility studies); the provision of better information about the geographical distribution of renewable resources; and the formalisation of a 5% target of "non-conventional renewable energy" (NCRE, i.e., non-large-scale hydro) into the portfolios of power companies. In addition, interagency coordination has begun to support RET deployment: the Chilean Ministry of Energy is cooperating with the Ministry of Public Goods to encourage the development of wind power projects on public lands, specifically by providing information about wind resource potential and facilitating a competitive, internationally open bidding process.

In addition to these policies directed at near-term deployment of RETs, other policies to support development of a durable institutional ecosystem have also been put in place. For example, in 2009 the Chilean government created the "Centre for Renewable Energy" which aims to encourage investment in NCRE projects, and to become a knowledge and technology transfer hub for Chile and the region.

Table 6: Examples of innovation policy tools in support of modernisation

Function	Example Policy Tools
Creating and Sharing New Knowledge	High-resolution RET resource assessments; Energy road-mapping and associated system analyses; Grid capacity and expansion studies.
Building Competence and Human Capital	Subsidies and incentives for education and training in power sector engineering, renewable resource assessment, project development and system engineering, finance, and international business.
Knowledge Diffusion / Creating Collaborative Networks	Hosting conferences in-country to showcase investment opportunities; Brokering international joint ventures; Supporting reverse trade missions to firms of interest.
Developing Infrastructure	Transmission expansion tailored to RE resources; Enhancements to shipping and logistics infrastructure.
Providing Finance	"Green" banks or other revolving credit facilities; Project finance loan guarantees; Credit guarantees or other instruments to improve creditworthiness of domestic firms participating in joint ventures.
Establishing Governance and the Regulatory Environment	Grid interconnection standards; Establishment of priority transmission zones; Enhancements to intellectual property protections and other determinants of investment climate.
Creating Markets	Feed-in tariffs; Renewable Portfolio Standards; Government/public procurement.

4.6. Green House Gas (GHG) emissions reduction

Reduction of GHG emissions for mitigating global warming is also an important driver for an increasing number of countries to seek innovation for RET deployment. While this goal can be an ultimate goal of the transition to renewable energy as a whole, this is particularly a concern for countries where a price is placed on carbon emissions through policy measures such as carbon tax or cap-and-trade system.

Examples

A study done by OECD on innovation in energy and climate change mitigation technologies (CCMTs) finds that the rate of innovation, which was indicated by patenting activities worldwide, has accelerated in many CCMTs in particular RET such as wind power, solar power, biofuels, geothermal and hydro. These technologies have come closest to being competitive because of mixed reasons including the cost reduction of RET and incentives (e.g. carbon credits) to clean energy. Such technological innovation can lower the cost of reducing GHG emissions. [60]

Countries that have committed themselves to reduce GHG emissions under international agreements, such as Kyoto Protocol, have made significant efforts to achieve their emissions reduction targets through the implementation of various policy measures, including carbon tax and cap-and-trade. This type of policy measures can play a key role to accelerate innovation in RET which produces little GHG emissions and could be used to offset emissions made on the basis of fossil fuels.

Technology Flows, Innovation Activities, and Innovation Capacity

A shift in relative prices often encourages technological changes. Increase in fossil fuels price in the market incentivises energy industries and firms to look for alternative and low-carbon energy sources, such as renewable energy. Under these circumstances, investment will be shifted to the RET development, thus stimulating innovation. Pricing a place on carbon emissions can therefore be one of the strongest incentive to encourage RET innovation in some countries.

Challenges

Meeting the long-term objective of reducing global GHG emissions with existing clean technologies is impossible without significant incentives, such as subsidies or high carbon prices. This is explained by the low prices of fossil fuels, which are calculated without taking into account internalised external costs. [61] Also, whereas pricing carbon can be a useful tool for the commercialisation and diffusion of technologies, it does not necessarily stimulate the early basic stage of the RET development. Breakthrough advances of RD&D of RET will thus also be critical for addressing GHG reduction throughout the whole technology life cycle.

Opportunities

Accelerating innovation in RET contributes to reduce GHG emissions, and mitigates climate change. This is one of the important goals to achieve not only at a country level, but also at a global level.

Another opportunity may be to induce technology and knowledge transfer among countries. The OECD study on innovation in energy and CCMTs also finds evidence of significant CCMT equipment and knowledge flows[13] across countries through technology trades and research cooperation.[62] Reducing GHG emissions through RET innovation will thus stimulate international technology and knowledge flows across the globe. An empirical evidence of this stimulus is that multinational companies are more often deploying low emission technologies even when there are no regulations in place to enforce these requirements.

Critical Steps

It is critical for countries to implement policy measures to incentivise the RET innovation. As mentioned, pricing carbon through carbon tax or cap-and-trade can be effective ways to stimulate the investment, RD&D and deployment of RET in the energy value chain. The steps for this portfolio are also closely linked to innovation policy tools supporting the energy cost reduction described in Section 4.3.

13 Technology transfers in the study defined as location of the duplicate applications for patented technologies considering the fact that patent protection may be sought in countries of potential market.

5. IMPLEMENTING STRATEGIC RET INNOVATION POLICY

This report outlines foundational concepts that underpin strategic RET innovation policy, and identifies key limitations of innovation policies to date: lack of policy durability, reliance on demand-side measures, too little attention paid to the needs of entrepreneurs, and lack of broad stakeholder engagement. Two key criteria for successful innovation policy development include: the ability to convene appropriate stakeholders around a shared vision, and the ability to anticipate and position a country to benefit from RET flows. This report makes the case that aligning RET innovation policy with broader energy development goals can assist in overcoming the typical shortcomings of RET innovation policy and meet these success criteria.

In summary, the recommendations of the report can be synthesised as a step-wise process for strategic RET innovation policy development:

1. Identify the energy development goal(s) within the region of interest;

2. Characterise the likely technology flows associated with these goals;

3. Identify the types of innovation activities that are appropriate for accelerating these technology flows;

4. Assess the innovation capacity needs necessary to achieve these innovation activities; and

5. Identify and convene the likely set of stakeholders involved in promoting policies to meet these innovation capacity needs.

Step 1 recognises the importance of articulating the enduring conditions under which RET innovation policies will be designed and implemented. Step 2 acknowledges that the diversity of RET options is quite broad, and that energy development goals will refine the set of options, privileging certain technologies over others. Step 3 further refines the analysis by identifying the types of innovation activities that will match the maturity of these technology flows. Step 4 begins to identify the specific innovation capacity requirements needed to support these technology flows. And finally, Step 5 places the final emphasis on engagement of all relevant stakeholders in devising a tailored policy portfolio to support these innovation capacities. This step-wise process aims to be flexible enough to apply to many contexts, in particular those outside of the BRIC and OECD settings. Additionally, this process aims to withstand many of the constraints that are at work in RET deployment and policy development.

Energy development goals are as diverse as cultures, economies, and electrical grids. The energy development goals outlined here are not meant to be exhaustive or mutually exclusive. Energy development goals are commonly found in novel combinations, and the diverse motivating forces behind energy development will certainly give rise to novel combinations of innovation policy instruments. Most importantly, the actual mechanics of knowledge and technology transfer also vary widely between different regional contexts and technology types.

Across all these settings, a common framework for discussing RET innovation policy will promote collaboration and enhance deployment outcomes. RET innovation policy development is an area deserving further research, and, as interest in RET deployment grows among countries at all stages of development, the practical challenges of crafting and sustaining such policy will be a critical concern. Anticipating that long-term energy development goals will strongly shape the formation of RET innovation policy enables decision-makers to craft policy solutions that will have enduring impact.

6. APPENDIX A. THE RET DEPLOYMENT CONTEXT

The RET deployment context – the constellation of economic, institutional, and social factors promoting and inhibiting RET deployment – has an important impact on entrepreneurial entry into a specific market, the types of innovation that might emerge, and the types of policy instruments that should be considered. This section aims to describe some of these factors at a general level, providing specific regional examples when applicable. The factors described in this section will play a key role in formulating strategic energy innovation policy portfolios tailored to national and sub-national contexts.

Four factors strongly impact the speed, scale, and characteristics of RET deployment: Energy Supply and Demand, General Absorptive Capacity, Renewable Energy Absorptive Capacity, and Policy Environment.

6.1. Energy Supply and Demand

A detailed and precise picture of energy supply and demand is important in evaluating policy options for RET deployment and innovation. For example, a demand profile weighted towards heavy industry will have different RET deployment prospects than a profile weighted towards commercial services or rural residential use. Likewise, a supply profile reflecting abundant domestic fossil resources will present different opportunities and challenges than a supply profile with ample wind and solar but few fossil resources. We discuss three specific factors within energy supply and demand: *Access to Electricity, Economic and Energy Demand Growth,* and *Domestic Energy Resources.*

Access to Electricity

Levels of electrification vary widely around the world and, as of 2009, approximately 1.3 billion people did not have access to electricity (see Table 7). Countries and regions with low rates of electrification may favour RET adaptation strategies that keep costs low, use proven technologies, and have some capability to operate without grid connection. Furthermore, even within countries with low rates of electrification, differences between urban and rural contexts are important for RET adaptation. In sub-Saharan Africa, roughly one in three urban residents does not have access to electricity. Market size in these urban areas is potentially higher than it is in rural areas, although tenuous property rights and other factors may complicate systematic energy development.[63] Perhaps a more important statistic is the electrification *growth* rate, or year-over-year change in electricity access, which may send stronger

Table 7: Access to Electricity and Rural and Urban Electrification Levels by Region, 2009

Region	Number of People without Electricity (millions)	Electrification Level (%)	Urban Electrification Level (%)	Rural Electrification Level (%)
Africa	**587**	**41.8**	**68.8**	**25.0**
North Africa	2	99.0	99.6	98.4
Sub-Saharan Africa	585	30.5	59.9	14.2
Developing Asia	**675**	**81.0**	**94.0**	**73.2**
China and East Asia	182	90.8	96.4	86.4
South Asia	493	68.5	89.5	59.9
Latin America	**31**	**93.2**	**98.8**	**73.6**
Middle East	**21**	**89.0**	**98.5**	**71.8**
Developing Countries	**1 314**	**74.7**	**90.6**	**63.2**
World Total	**1 317**	**90.5**	**93.7**	**68.0**

signals about market potential to energy firms and policymakers. In any case, RET deployment and innovation strategies for electrification will be impacted by the level and type of energy access.

Source: IEA World Energy Outlook 2011

Economic Growth and Energy Demand Growth
Energy use has a strong relationship to economic output,[64][65]14 and rapidly expanding markets present attractive investment opportunities for domestic and foreign firms. From a policy perspective, in middle- and low-income countries where economic growth is rapid, the imperative to ensure low-cost energy may be higher, given a reluctance to place a drag on economic growth (see Text Box 1). This presents both an opportunity and a challenge to RET deployment. To the extent that RETs can be offered as reliable sources of stable domestic supply capable of providing cost-effective energy, there may be an opportunity to leverage broader investments in energy supply to accelerate RET deployment. To the extent that growth is pursued via the lowest-cost conventional energy sources, the economic growth imperative represents a challenge to RET deployment.

Domestic Energy Resources
The magnitude and cost of both fossil and renewable resources impact on the prospects for RET deployment. In countries with ample coal, gas, and/or petroleum, the incentives for RET deployment may be lower because domestic fossil resources represent both a low-cost energy source and a significant contributor to the local economy (see Text Box 1). However, a difficult decision – whether to sell fossil resources for income or burn them for electricity and transport – is increasingly presenting itself. For various reasons, fossil-rich nations such as Saudi Arabia, Indonesia, and the United Arab Emirates have begun to prioritise RET deployment.

The quality and geographic distribution of renewable energy resources also has a strong impact on RET deployment in a given country or region. Nations with ample commercially developable resources have comparative advantages over those with fewer. The presence of ample renewable resources increases the chances that RETs will play a meaningful role in energy and economic growth planning. Countries with low levels of RE resources face the challenge of participating in the RET sector primarily through discrete roles in RET supply chains and services.

6.2. General Absorptive Capacity

Innovation arises from "systems of innovation,"[66] and various analysts have studied the relationship of such systems to the specific context of RET innovation.[67][68][69] The systems view suggests that existing stocks of infrastructure, institutional capacity, and human capital both facilitate and constrain the absorption of RETs and play a key role both in short-term adaptive deployment and in laying the groundwork for medium-term innovation capacity.[70] A range of factors comprise the absorptive capacity of a region or country, and an exhaustive description is beyond the scope of this report. Instead, we focus on the key factors that are relevant to the evaluation of policy instruments for RET deployment and innovation.

In a broad sense, absorptive capacity is a measure of how easily new technologies, methods, and business models can be assimilated into an economy. The generally accepted theory of absorptive capacity is that it is largely a function of prior related experience.[71] New methods of investigating this theory have emerged – for example, the *Product-Space* method devised by Hidalgo et al. (2007).[72] By comparing change in production patterns over time, they suggest a way to quantitatively measure the difficulty of moving from making one product to making another. Their research appears to confirm the conventional wisdom: prior economic activity creates favourable conditions and available pathways for future growth.

More recently, economists have integrated this observation into useful frameworks for crafting targeted support for specific industries – in other words, frameworks for active government design of industrial policy.[73] The key observations from the work of Hidalgo et al. and Lin et al. are that policies to encourage industrial expertise must be grounded in a thorough analysis of existing capabilities and competitive advantages. Tawney et al. (2011) reiterate this advice in their description of the development of RET innovation policy.

14 Research indicates that this relationship is somewhat complex, as technology change can decouple the two, and causality can flow three ways: GDP growth causing energy use, energy use causing GDP growth, and bi-directional causation. Nonetheless, the link between GDP and energy use is generally robust. For more discussion, see Warr, B. S., & Ayres, R. U. (2010). Evidence of causality between the quantity and quality of energy consumption and economic growth. Energy, 35(4), 1688–1693. doi:10.1016/j.energy.2009.12.017 and Soytas, U., & Sari, R. (2003). Energy consumption and GDP: causality relationship in G-7 countries and emerging markets. Energy Economics, 25(1), 33–37. doi:10.1016/S0140-9883(02)00009-9.

Determinants of general absorptive capacity include, but are not limited to, the following overarching factors:

Human Capital

- General education, literacy, and school enrollment.
- Status of labour capacity (skills and cost).
- Level of tacit scientific and engineering knowledge.
- Level of codified scientific and engineering knowledge.
- Level of entrepreneurship.

Institutional Capacity

- Quality and transparency of regulatory and governance structures.
- The "cost of doing business".[15]
- Rule of law and quality of recourse to the system of courts (e.g., for intellectual property rights protection or contractual disputes).
- Availability of public financing mechanisms (e.g., taxing and bonding authority).

Financial Capacity

- Presence and quality of domestic financial institutions, ranging from banks to risk capital.
- Openness to foreign direct investment.
- Presence and quality of micro-finance institutions.
- Presence and quality of entrepreneurship.

Infrastructure Capacity

- Presence and quality of existing infrastructure.
- Presence and quality of existing manufacturing or other industrial capital.

Significant research into the quantitative indicators can be used to measure each of these factors.[16] While this sort of analysis is beyond the scope of this report, detailed data collection about national and local absorptive capacity is likely conducive to effective innovation policy-making.

6.3. RET Absorptive Capacity

The specific factors determining RET absorptive capacity are related to, but distinct from, those determining general absorptive capacity. RET absorptive capacity is sensitive to a range of specific technical, social, and industrial factors that facilitate or constrain RET deployment. Not least of these are ease of grid interconnection, clear standards for device performance and interoperability, as well as the presence of engineering knowledge. Determinants of general absorptive capacity include, but are not limited to, the following overarching factors:

Human Capital

- Presence of post-graduate attainment in business, law, and various engineering fields: electrical, mechanical, civil, chemical, computer, or aerospace engineering.
- Level of tacit energy system engineering knowledge.

Institutional Capacity

- Quality and transparency of energy regulation.
- Transparency of grid interconnection processes.
- Level of recourse to courts or arbitration in cases of energy-specific contractual disputes (e.g., with regard to power purchase agreements).

Financial Capacity

- Extent and quality of construction and project development finance.
- Extent and quality of micro-finance capacity for energy projects.

15 See for example the annual "Doing Business" reports issued by the World Bank and the International Finance Corporation. http://www.doingbusiness.org/reports/global-reports/doing-business-2012

16 See for example Narula, R. (2004). "Understanding Absorptive Capacities is an "Innovation Systems" Context: Consequences for Economic and Employment Growth." Danish Research Unit For Industrial Dynamics Working Paper No 04-02. December 2003.

Infrastructure Capacity

- Extent and quality of adequate electrical grids.
- Extent and quality of ancillary roads, railways, ports, and waterways.
- Presence and quality of existing energy technology manufacturing or other industrial facilities.

6.4. Policy Environment

Existing policies can strongly influence national and regional capacity for RET deployment. At the most general level, fossil energy subsidies, whether in the form of transportation fuel subsidies or price-caps on electricity generated from fossil fuels, can strongly impact on the business case for widespread RET deployment. Additionally, the presence of a national energy policy, whether it includes specific incentives for RET deployment or not, is also a strong determinant of RET absorptive capacity.[74][70][25]

The presence of existing economic development policies may also shape the landscape of RET deployment, often in positive ways. For example, policies to create regional economic clusters are already operating in many developing countries,[75] which can provide insights into the type and location of expected electricity demand growth. Additionally, existing policies to promote technical education or university enrollment can provide much-needed absorptive capacity for RET innovation. The extent to which RET innovation policy can link itself to complementary policies and programmes is important, especially given the range and magnitude of the various constraints outlined above.

7. APPENDIX B: THE RENEWABLE ENERGY INNOVATION POLICY DEVELOPMENT CONTEXT

Appendix A outlined factors that promote and inhibit RET deployment in various contexts. The opportunities and constraints at the level of policy development are also relevant to the development of effective innovation policy. Recent literature describing best practices of RET innovation policy[7] often suggests an intensively analytical process loop: assess the business and technology landscape, design a policy, implement that policy, evaluate it, and repeat. Interviews and a literature survey conducted for this report did not find strong evidence of a fully functioning and sustained version of this iterative process in any non-OECD countries. Some observers note that many OECD countries struggle to achieve sustained coherence in innovation policy – evidence of such processes is scarce. To some extent, this lack of systematic innovation policy-making is counter-intuitive because there are strong incentives to succeed at innovation, and policy-makers would be expected to benefit from establishing leadership in RET innovation. The most likely explanation therefore may be that the general absence of deliberate, methodical, and iterative innovation policy-making is a product of real-world constraints at work in the policy development context.

Like all policy-making, innovation policy is typically created amidst competing priorities and with scarce resources. Surveys and interviews conducted for this report reinforce the notion that decision-makers respond to these constraints through creativity, improvisation, and *ad hoc policy* processes. An understanding of these constraints may help explain the types of policies that are created today, and it may help catalyse a vision of the actions that can be taken at the national and international levels to loosen some of the more binding constraints. This section identifies three stages of policy that feature different constraints: *formation, execution,* and *evaluation*. Formation refers to the process of designing appropriate policy. Execution refers to the process of implementing and maintaining policies. Evaluation refers to the process of measuring the impacts of policies.

7.1. Formation Constraints

Budgetary Resources

The national or regional balance sheet is a common constraint to RET innovation policy. Tactically, this constraint complicates innovation policy-making both in terms of the overall adequacy of funding and in terms of its consistency over multiple years. Strategically, this constraint places a downward pressure on the allocation of innovation planning resources, limiting the resources with which innovation policy-makers can invest in proper planning. This in turn limits the extent to which policy formation best practices (e.g., technology and capability landscape assessments, industry workshops[7]) can be supported, if at all.

Technology Boundary Definition

In contrast to many other industry sectors (e.g., pharmaceuticals or semiconductors), technology innovations in the energy sector are diverse and difficult to set boundaries for,[76] a feature that adds complexity to policy planning, execution, and assessment. For example, an innovation in methods of genetically modifying the bacterium E. coli for more efficient production of insulin might unlock price reductions in second-generation biofuels. Similarly, advances in seismic testing for natural gas might reduce costs for the exploration of enhanced geothermal systems.

Targeting Successful Innovators

In addition to the observed permeability between energy technology domains, the long life cycle from innovation to commercialisation makes it difficult to identify and target the best organisations for support. Innovations may originate from a wide range of public and private organisations within a given technology. University laboratories may be best equipped to advance fundamental knowledge of organic molecule photosensitivity, while commercial firms are applying novel manufacturing methods for low-cost PV racking. Recent research into the organisational sources of energy innovation indicates that high-impact innovations in a single field commonly emerge from both public and private research organisations.[77]

Distributed Policy Responsibility
The responsibility for innovation policy in general, and energy innovation policy in particular, is often fragmented and unclear. At the national level, innovation issues overlap with the jurisdictions of ministries of energy, technology, public lands, commerce, finance, and other agencies. Additionally, legislative approval is often required for major supply-push and demand-pull policies. As policy roles and responsibilities become clearer and more binding, consistent and durable innovation policy options become more feasible.

Turnover
There is consensus that consistent, long-term policy stability promotes effective innovation policy. In the real world, this is often quite difficult. The leaders at the top of many national energy ministries are political appointees, and they rarely serve more than five years. Staff within agencies may also carry significant embodied knowledge that is difficult to recreate. Turnover may bring different skill sets, policy priorities, and technological preferences, frustrating the establishment of consistent and durable RET innovation policies.

National Industrial Policy
RET innovation policy formation is typically viewed as a sub-category of other national priorities, for example economic development, competitiveness, or industrial policy. While few policy-makers reject the importance of either "competitiveness" or creating an "innovation system," all still face very real questions about how to address this challenge; which, if any, industries to focus on, and the type, magnitude, and duration of support. For many countries considering cluster-based support instruments, this challenge may boil down to broad questions such as: Should loan guarantees be directed towards the support of textile companies or biofuel companies? Should support be directed towards a semiconductor chip factory or a PV manufacturing factory?

Uncertain Evaluation Criteria
In the domain of pollution and emissions control, policy instrument selection benefits from generally agreed-upon evaluation criteria, including cost-effectiveness, distributional equity, the ability to address uncertainties, and political feasibility.[78] RET innovation policy presents more ambiguity about the defining metrics by which it should be evaluated, which frustrates effective formation and rigorous evaluation of policy.

International Trade and Tariff Rules
To the extent that policy-makers hope to protect domestic markets as sources of demand for domestic innovators, international trade regimes may constrain their policy options. The 2011 Asia-Pacific Economic Cooperation (APEC) Leaders' Declaration[79] reiterated adherence to non-discriminatory trade and innovation policies, affirming that member countries will "[r]efrain from adopting or maintaining measures that make the location of the development or ownership of intellectual property a condition for eligibility for government procurement preferences, without prejudice to economies' positions in the WTO". This language is probably aimed at "local content requirements" enacted to favour components sourced in-country, effectively putting national economic development above international free-trade obligations. Such non-tariff instruments (e.g., local content requirements) have emerged in many countries and subnational jurisdictions (e.g., Brazil, China, the Canadian province of Ontario, and various states of the United States), although they are likely to face stiff review from international trade bodies.

7.2. Execution Constraints

Execution Lag
Mismatches between various planning functions and real markets may frustrate the formation and execution of innovation policy, adding risk to policy processes. For example, a thorough assessment of the solar PV market and supply chain carried out in 2008, a time of very high silicon prices, guided U.S. government support for non-silicon PV manufacturer Solyndra. The shocks to the PV supply chain that unfolded between 2009 and 2011 reduced silicon prices by more than 50% and dramatically impacted on the viability of the Solyndra loan guarantee investment.

While the mismatch in timing between investment due diligence and global commodity markets represents a high-profile example of execution lag, more mundane mismatches are often at work. For example, individuals charged with RET innovation policy planning may, or may not be, around to continue implementing those same policies three or five years later.

Investment absorptive capacity: human, social, institutional, and financial

The level of innovation policy effectiveness achieved depends critically on the financial, institutional, human, and social capital bases of regions and nations. Many of the regions that stand to benefit most from energy innovation are also least able to absorb policy support. This "innovation paradox" has also been defined as "the apparent contradiction between the comparatively greater need to spend on innovation in lagging regions and their relatively lower capacity to absorb public funds earmarked for the promotion of innovation and to invest in innovation-related activities compared to more advanced regions."[80]

Opaque "Installed" Costs

Factors impacting on the LCOE of RETs include siting and permitting approvals, labour wages and expertise, cost of capital, incentives, and operating costs if necessary. The magnitude of these factors varies widely within and among countries, and they are often difficult to ascertain, complicating the process of policy-making and the cost-benefit analysis undertaken by firms before entering the market. As noted above, the IRENA is commissioning surveys of costs around the world to help provide accurate information for consumers, project developers, investors and policy-makers.

International Currency Markets

Export power – the competitiveness of products sold abroad – depends highly on currency valuations. For better or worse, a country or region with a high proportion of economic activity devoted to exports is particularly exposed to swings in currency markets. An innovation policy that focuses on reducing the cost of RETs for export may be largely cancelled out by currency market changes.

7.3. Evaluation Constraints

Data Quality

Many observers have noted the difficulty of collecting data that enables evaluation of RET innovation policy.[81] Barriers to data quality are formidable and are unlikely to be overcome in the short term. At the early stages of technology development, private company R&D budgets would be useful in gauging the impact of a given innovation policy, but since these budgets are business-sensitive they are unlikely to be widely shared. Also, at this stage the spillovers of innovations between technology domains frustrate the efficient tracking of publications, patents, and commercialisation events. For example, support to solar PV research might yield innovations whose impact is felt most directly in semiconductors, and vice-versa; aeronautics in wind; oil and gas in geothermal; biotech and agriculture in biofuels; and so on. Finally, the challenge of linking a patent to its final commercial manifestation shows no signs of yielding to rigorous data tracking any time soon.

Execution Lag

Just as delays between design and enactment can frustrate effective, timely policy implementation, similar delays between execution and evidence of tangible results frustrate rigorous policy evaluation. Sustained, consistent data collection efforts over five or ten years would support policy impact evaluation, but such durable data collection may challenge resource-constrained governments.

Establishment of Causality

Even in the case of clear examples of innovation arising in a country that has implemented best-practice RET innovation policy, it is very difficult to robustly prove causation of a given innovation to a particular policy or portfolio of policies.

7.4. Policy Interactions and Inter-policy Competition

Competition and interaction between various policies represent a final constraint on RET innovation policy-making. Regarding competition, more than USD 409 billion was spent globally in 2010 to subsidise fossil energy sources, mainly as a support mechanism for people on low incomes. As 2011 events in Nigeria demonstrated,[17] attempts to remove fuel subsidies carry significant political risks. Even if removing fuel subsidies is not an option under consideration, their continued existence may limit the effectiveness of RET deployment and innovation policy.

Regarding policy interaction, some researchers in environmental economics (mainly focused on RET deployment policies) recently cautioned that overlapping policies at the state and national levels can increase compliance costs[82] and can even be counterproductive.[83] Other researchers

17 Protests in Nigeria: Let them have fuel. (2012, 21 January). The Economist. Retrieved 10 February 2012 from http://www.economist.com/node/21543199.

are less skeptical of overlapping policies, suggesting instead that the net effect depends on each context, and proper policy evaluation should attempt to consider all existing policies and potential interactions.[84] While such analysis would certainly be valuable, it is typically a complex task, and the ability to carry it out represents an important constraint on effective policy-making.

Drawing on the WRI policy toolbox discussed in Section 3 and the constraints described here in Appendix B, a brief summary of policy tools, their potential constraints, and corresponding assessment needs is outlined in Table 8.

Undertaking each and every assessment in Table 8 may be beyond the jurisdiction of many energy policy-makers, and furthermore, the cost-benefit analysis may not support such an effort in a fiscally constrained environment. Here the importance of multi-stakeholder involvement is apparent, as parallel planning and assessment work may often be performed under the umbrella of other policy areas, especially education, economic development, international trade, and the electricity sector broadly. Section 6 of this report includes a discussion of specific strategic portfolios that can begin to leverage these macro-policy areas for the benefit of RET innovation.

Table 8: Innovation Policy Tools, Constraints, and Assessment Needs

Example Policy Tools	Policy Constraints	Assessment Needs
Subsidies and incentives for new research	Funding; Institutional and technical capacity Competing national research priorities (e.g., pharmaceuticals).	International supply chains; Domestic research, development and demonstration (RD&D) capacity; Commercialisation capacity; Policy monitoring capacity.
Contests and prizes	Securing long-term funding; Effective marketing; Difficulty in evaluating success.	International supply chains; Domestic RD&D capacity; Commercialisation capacity.
Intellectual property protection and enforcement measures	Funding for enforcement (courts).	Gap analysis of court system; International (i.e., WTO or bilateral trade agreement) obligations.
Subsidies and incentives for education and training	Funding; institutional capacity; Difficulty in evaluating success.	International supply chains; Domestic education capacity.
Visas for advanced degree candidates	International competition for immigrants; Existing immigration policies.	Existing immigration policy; State and local academic enrollment capacity.
Joining or initiating international cooperation	Funding; technical capacity; intellectual property protection.	Gauging interest from existing industry and government stakeholders.
Supporting industry associations	Coordination capacity; funding; level of interest from domestic industry; technical capacity.	Gauging interest from existing industry stakeholders.
Public-private partnerships	Funding; Appropriate accountability measures; Difficulty in evaluation; Attractiveness to FDI (cost of doing business).	Assessing landscape of existing partnerships; Assessing capacity of firms and government agencies.
Incentivising private development	Funding; Private sector capacity; Attractiveness to FDI (cost of doing business); Appropriate accountability measures; evaluation.	Assessing competing and interacting policy incentives.
Investment in public infrastructure	Funding; Jurisdictional (federal vs. state) conflicts; Accountability.	Grid integration studies; Logistics gap analysis.
Providing finance	Funding and financial institutional capacity; International partnerships for financing; Complementary legal and insurance capacity.	Analysis of funding needs and existing capacity; Gap analysis of legal and insurance capacity.
Establishing governance and the regulatory environment	Technical capacity for standards development; Ability to enforce regulations and collect taxes; Ability to mandate and enforce energy targets.	Critical needs assessment of regulatory capacity broadly as well as in electric sector.
Creating markets	Funding; Ability to enforce regulations and transparently distribute subsidy funds; Willingness and ability of project developers, electrical utilities, and/or consumers to participate.	Assessing current market structures, likely market interactions and competing subsidies; Assessing ability of electricity companies and/or consumers to participate.

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