IRENA
International Renewable Energy Agency

RENEWABLE ENERGY TECHNOLOGY INNOVATION POLICY

A PROCESS DEVELOPMENT GUIDE

JANUARY 2015

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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EXECUTIVE SUMMARY

This report is intended to serve as a guide for policy makers in implementing national or sub-national policies to support innovations in Renewable Energy Technology (RET). It provides a structured process for RET innovation policy development and *inter alia* attempts to answer diverse questions that may be of interest to policy makers; for example:

- What roles do existing resources and capacities play in shaping innovation policy?
- What types of innovation are most suitable for each designated situation?
- How can innovation policies be aligned with overarching governmental policy objectives in order to promote their success?
- Which renewable energy (RE) technologies should be prioritised?
- What specific policy instruments should be applied and who should be involved in their design, implementation and governance?
- What strategic signals should be sent to external stakeholders to optimise this approach to innovation?

The policy development guidelines contained in this report allow for significant customisation according to specific regional, national or sub-national contexts. The principles outlined here apply broadly to many renewable energy industries, as well as to a wide range of countries with varying energy and economic endowments. The report also suggests potential leverage points for cooperation, knowledge sharing and policy diffusion within the IRENA membership network.

"Renewable Energy Innovation Policy: Success Criteria and Strategies", an earlier discussion paper published by IRENA (IRENA 2013), proposed a basis for understanding the contextual variables that shape RET innovation capacity and also provided broad principles for policy design. This report builds on that previous work, and provides greater structure by outlining a Renewable Energy Technology Innovation Policy ("RETIP") process for the development of policies to foster innovation. The RETIP process is one way to view the complex landscape of innovation. Although many other innovation policy approaches have been suggested, this report makes an effort to identify these whenever possible. Specifically, the RETIP process aims to *anticipate* key questions and challenges for IRENA member countries.

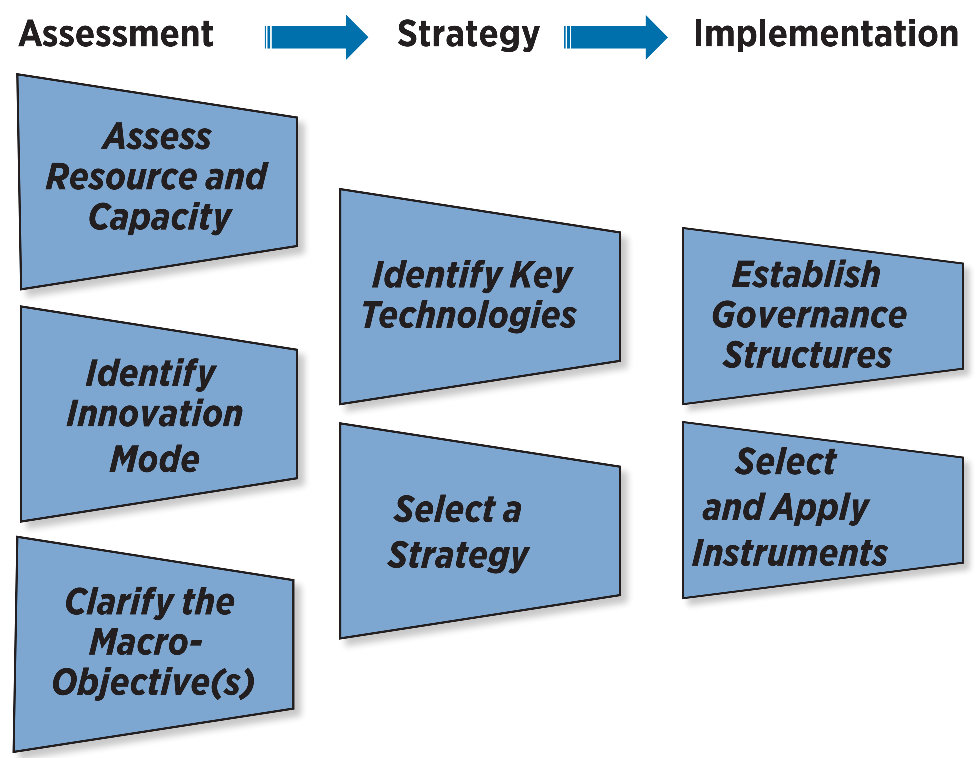
Overview of the RETIP Process

The capacity to innovate in renewable energy technologies is the result of many factors that vary widely across national and sub-national contexts. Regardless of the technology in question, support for—and coordination among—economic, educational and energy policy domains is crucial to the creation of *effective* RET innovation policies. These are generic *foundational* conditions for successful innovation policy. In addition, *specific* policies are often necessary; these must be customised to bolster the unique capacity development needs in each country and to be appropriate for the technologies of choice. These *sectoral* innovation policy conditions constitute an important focus of the RETIP process.

To structure the approach to crafting innovative policy portfolios, the RETIP process articulates a three-stage process:

- The **Assessment Stage** focuses on undertaking a structured evaluation of existing resources and capacities, identifying appropriate "modes" of RET innovation and clarifying the overarching policy goals that serve as long-term drivers of innovation policy.
- The **Strategy Stage** focuses on identifying key technologies that are well-suited to a particular context and on crafting an overarching policy strategy that supports innovation in these domains.
- The **Implementation Stage** focuses on selecting and applying specific policy instruments while establishing appropriate governance structures to promote the implementation process.

Figure ES 1: The Three Stages of the RETIP Process: Assessment, Strategy, and Implementation



These three stages serve as an analytical or deductive "funnel", moving from general to specific considerations of innovation policy. The RETIP process aims to cover the entire innovation policy development cycle: from evaluating specific existing innovation capabilities to identifying innovation opportunities to selecting appropriate policy instruments and finally to clarifying roles and responsibilities in support of effective implementation.

The report also applies the RETIP framework as a lens to examine how innovation policy has emerged in three very distinct geographic settings — Chile, Brazil and Germany. In each of these cases, the innovation policy was not centrally managed through a process like RETIP; rather, it emerged from the actions of many (sometimes competing) stakeholders. These case studies are meant to illustrate the issues and challenges that have arisen in crafting innovation policy and to illustrate how the RETIP stages (*i.e.* assessment, strategy and implementation) can provide an organising framework for development.

The RETIP process is designed to benefit countries by surveying a broad range of literature and case studies, clarifying priorities and helping to organise the process of innovation policy development in an otherwise highly complex field. The interrelated assessments within each stage are structured to identify the fundamental innovation needs of IRENA Members in each sector. Finally, the RETIP process should provide a common framework and vocabulary to support collaboration, learning, research and policy diffusion.

While the innovation policy outcomes of the RETIP process will vary widely in keeping with national and local factors, the following generic messages are important for innovation policy makers:

- **RET innovation opportunities are as diverse as are IRENA's Members.** The RETIP process emphasises that RET innovation may occur in *any* country and/or *any* setting. While the challenges to RET deployment are diverse, it is precisely the role of innovation policy to unleash the forces of creativity to overcome these challenges. From the frontiers of scientific knowledge to the factory floor, from dense urban centres to remote rural communities, policy conditions that encourage innovation are a central tool in support of energy transformation.

- **Context matters as much or more than technology.** The development of targeted RET innovation policies demands careful attention to contextual factors. In fact, in many cases, specific factors regarding existing capabilities, policy priorities and governmental bodies are more important to policy development than the nature of the specific technologies under consideration. The RETIP process aims to elevate the relative importance of contextual factors in the development of innovation policy over those of technology-specific considerations.
- **Coordinated governance is important.** All policies pre-suppose the institutional capacity and coordination required to achieve successful implementation. Innovation policy is uniquely dependent upon coordination since diverse domains impact the conditions for innovation. The coordination challenge has both "horizontal" and "vertical" dimensions. The *horizontal* challenge is to coordinate diverse policy domains, such as energy, education, labour, trade and environment, as well as collaborating with the private and non-governmental sector. The *vertical* challenge is to coordinate the appropriate roles and responsibilities of various levels of government (*e.g.* local, state, national and supranational policy bodies). Careful consideration of governance in the light of capacity constraints and coordination costs will result in more appropriate and robust innovation policies.
- **Assessment can pinpoint critical areas of policy focus.** "Real world" innovation policy development—like innovation itself—is dynamic and non-linear. While the RETIP process provides a step-by-step framework for understanding conditions that inform innovation policy, this does not imply that innovation policy development itself is linear. If anything, the RETIP process describes a process that can and should be iterated and improved upon over time. More importantly, the RETIP process brings together a broad body of literature and experience to produce a clearer overall picture of innovation policy. In this way, IRENA Members can clarify critical focal areas. The goal is that holistic consideration of the variables outlined in the RETIP process will result in a more comprehensive, balanced and sustainable approach to innovation policy.

The report is organised as follows: Section 1 introduces the guiding principles and outlines of RETIP process. Section 2 introduces the Assessment stages of the process, focusing on customised resource and capacity assessments to provide orientation in the RET innovation landscape. Section 3 outlines the Strategy stage of the process, detailing considerations for selecting specific innovation strategies and the process of identifying key technologies. Section 4 explores the Implementation stage of the process, briefly discussing the toolbox of innovation policy instruments and discussing practical governance considerations to help establish policy roles and responsibilities. Section 5 presents three country case studies of RET innovation policy with a focus on the historical evolution of actual policy ecosystems. Section 6 concludes with recommendations for IRENA Members in applying the RETIP process. Appendix A provides a candidate list of data sources for RETIP background assessments. Appendix B provides a broad survey of example innovation policy instruments.

1 OVERVIEW OF THE RETIP PROCESS

The Renewable Energy Technology Innovation Policy (RETIP) process is founded upon the following two assumptions:

1) A myriad of innovation opportunities *exist* across the value chains of various renewable energy technologies (RETs); and
2) These innovation opportunities are strongly *affected* by contextual factors.

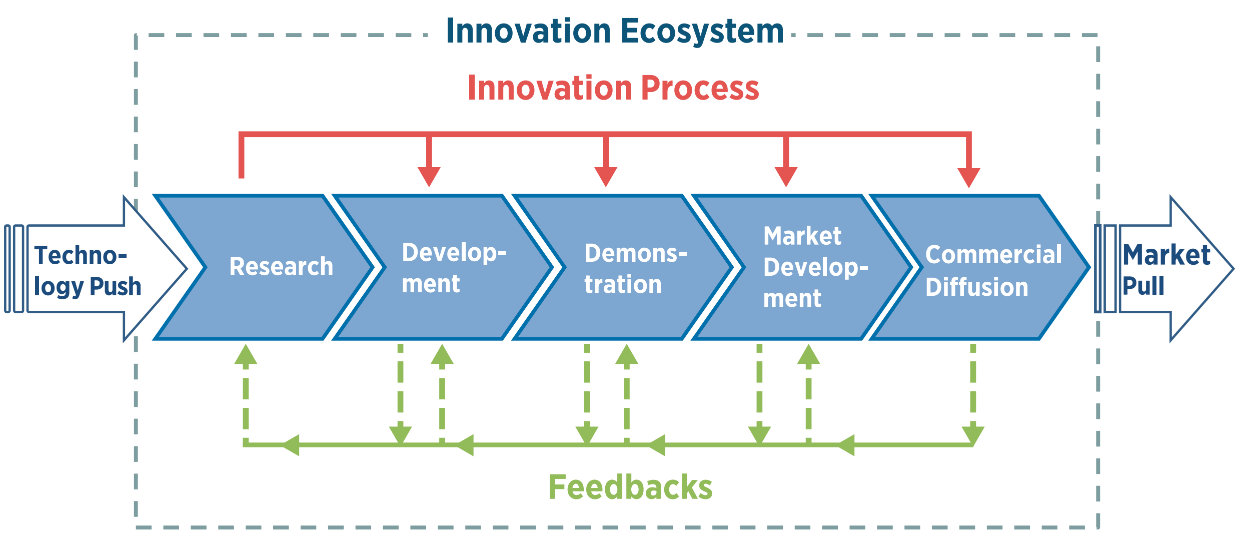
This process guide seeks to enable policy development across the spectrum of RET innovation opportunities, taking into consideration this diversity of contextual factors.

Typically, in the *abstract* conventional model, technological inventions are thought of as moving in linear fashion from high-technology research laboratories through early stage commercialisation and finally into the markets. However, in the *real* world, RET innovation is more complex, often following less linear pathways, emerging through networks of stakeholders, and frequently involving feedback loops that produce incremental improvements and dynamic business model innovations. Figure 1 illustrates this more dynamic view of innovation.

The variety of innovation pathways reflects the fact that the "hardware" itself is not purely physical, but evolves itself within the specific policy context and set of systems, embodying the knowledge required to create the hardware. Furthermore, it requires a collection of skills and knowledge in how to adopt, implement and adapt the technology (Bell and Pavitt, 1993; D. G. Ockwell *et al.* 2010, as discussed in Byrne *et al.* 2011).

Constraints: Various other factors are important to consider in crafting RET innovation policy. Firstly, there are economic factors that constrain investment in RET innovation. Specifically, RET innovators are not always

Figure 1: Illustration of a dynamic, ecosystem view of innovation



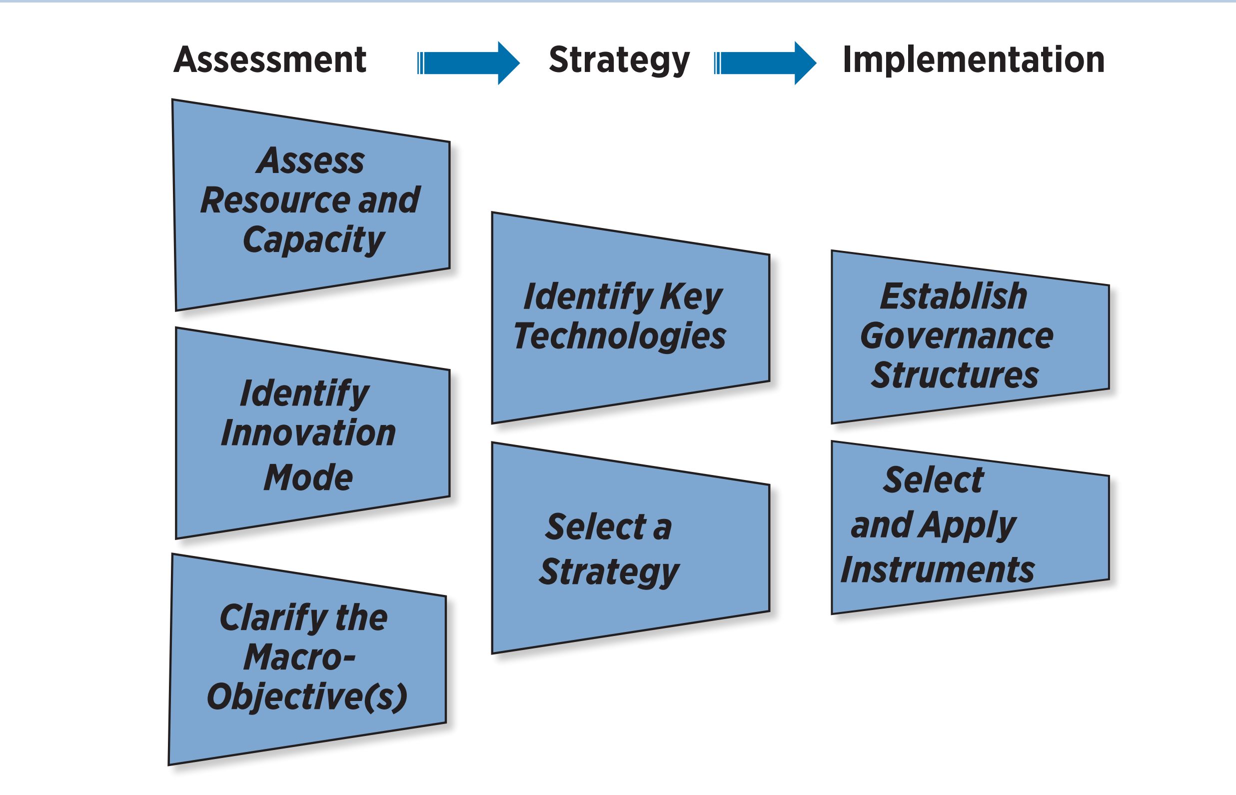
able to profit from the positive effects of their investments, which reduces the incentive to invest in RET innovation. This is a factor both at the innovation stage (*e.g.* it is difficult to prevent other actors from copying and benefiting from "frontrunner" R&D efforts) and at the diffusion stage (where reductions in negative externalities do not necessarily translate into profits). These two disincentives to innovation investment are well known as the *'double externality'* problem (Rennings, 2000). Beyond these externalities, RET innovation takes place in deeply embedded infrastructure systems, which can strongly constrain the pace and scope of innovation opportunities (see for example Musiolik and Markard, 2011). The case studies in Chapter 5 explore the various pathways that RET innovation can take through these rugged landscapes.

The diverse nature of RET innovation reinforces an inclusive, "networked" view of innovation that has been gaining support for at least two decades (Bell and Pavitt, 1993). This guide adopts the broader definition of innovation, which is compelling for IRENA membership, and expands innovation from an exclusively R&D domain to a more universally accessible policy and economic development challenge.

The second central principle of this guide is that specific, contextual factors matter deeply when crafting innovation policy. Existing resources, human and institutional capacities, energy needs, stakeholder networks, etc., are all crucial. Decision makers who understand these multiple dimensions—through a rigorous assessment of technical, institutional, human and financial capital—can make better decisions. The decision guide itself provides a structured process for identifying RET innovation opportunities, evaluating policy options and developing contextually appropriate approaches. This process consists of three stages, as illustrated in Figure 2, and described below.

1) The **Assessment Stage** focuses on describing a structured evaluation of foundational resources and capacities. Specifically, it articulates three inter-related evaluations:
   - *Assessing Resource and Capacity* (comprises an analysis of foundational conditions for

Figure 2: The three stages of the RETIP process



innovation, and inform gaps and opportunities in RET innovation policy development.

- *Identifying Innovation Modes* provides broad indications of the level of "fit" between capacities and RETs.
- *Clarifying Macro-objectives* serves to stabilise innovation policy by aligning it with long-term, broadly shared policy goals.

2) The **Strategy Stage** focuses on clarifying more specific policy strategies in support of innovation. Specifically, the RETIP process suggests two inter-related evaluations:

- *Identifying Key Technologies* in which the full range of RETs available for innovation activities is screened according to the findings of the Assessment Stage.
- *Selecting Innovation Strategies* in which policy makers assemble coherent approaches for portfolios of innovation policies.

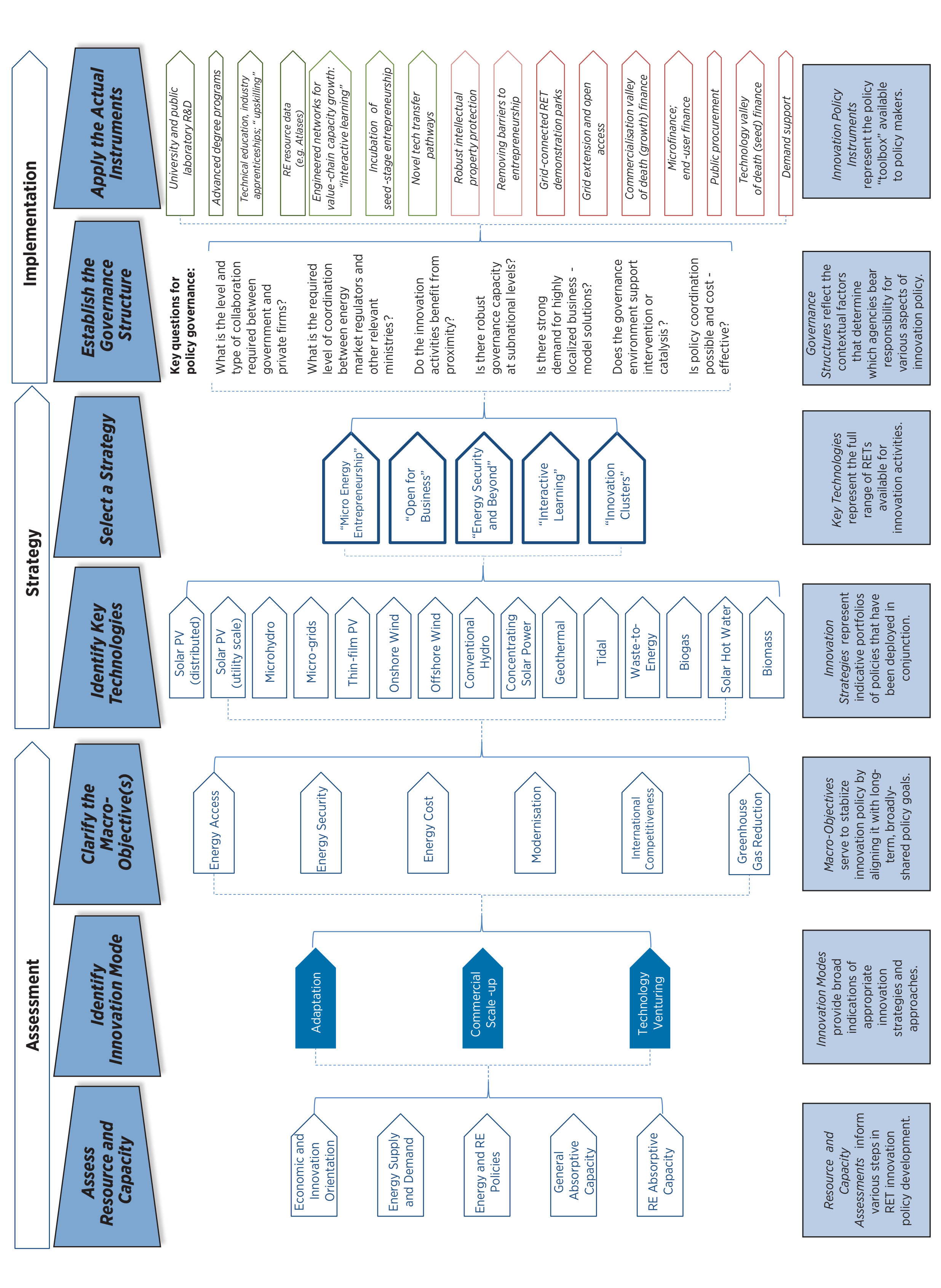
3) The **Implementation Stage** focuses on selecting and applying specific policy instruments. Specifically, the RETIP process suggests two inter-related steps:

- *Establishing Governance Structures* in which the roles and responsibilities for various aspects of innovation policy are clarified.
- *Selecting and Applying Innovation Policy Instruments* in which specific options from the policy "toolbox" are chosen for implementation.

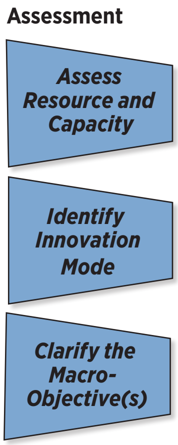
Together, this three-stage process aims to be *specific* enough to produce policy insights and *general* enough to be relevant for all IRENA Members. While the RETIP process is articulated in a linear, multi-stage fashion, it should be kept in mind that, in reality, innovation policy development will evolve in cycles with numerous cross-linkages and feedback loops between these stages. The three-stage process is utilised as a rational model to clarify priorities and interdependencies. Within this guide, each of these steps is discussed as a means to support the policy development processes while attuned to local factors and global energy supply chains. These categorisations are investigated in greater depth in later Sections. A more detailed overview of the RETIP stages, associated evaluations and key concepts is illustrated in Figure 3.

Together, these steps comprise a common framework and language for RET innovation policy, supporting both international dialogue and learning in this important domain, as well as supporting policy development in a way that builds on national strengths and aligns with existing macro goals and stakeholder networks. These steps also explicitly underscore that innovation is not only a research and development (R&D) activity to be carried out in large research institutions, but simultaneously an activity that can be carried out across all international settings (*e.g.* "adaptive" business model innovation) that can take root in developing economy contexts. We now turn to each stage in more detail.

Figure 3: Illustrative guide to the RET innovation policy development process

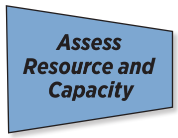


2 ASSESSMENT STAGE: ASSESSING RESOURCES AND CAPACITIES, IDENTIFYING INNOVATION MODES AND CLARIFYING MACRO ENERGY GOALS



This section explores the Assessment Stage of the RETIP process, which focuses primarily on targeted evaluations of fundamental capacities and drivers for RET innovation. While the principles that underlie successful innovation policy are, by and large, identical, each country exhibits unique circumstances with regard to its macro energy goals, innovation capacities and stakeholder networks. These circumstances strongly shape the available policy options. Shared circumstantial similarities with other countries may allow policy makers to benefit from patterns, affinities and points of collaboration based on similar structural, resource, and market contexts. These first steps help in identifying such unique traits.

2.1 Assessing Resource and Capacity



Innovation is not an activity solely reserved for the most developed countries; rather, it is a participatory one from which *all* countries can benefit. Nonetheless, important distinctions exist in crafting innovation policy tailored to local contexts. In order to provide more contextually appropriate policy guidelines for IRENA Members, this report proposes that countries base their innovation policy development on a broad and rigorous assessment of their own various resource and capacity indicators. This process of self-assessment and self-orientation contributes to a better understanding of the subsequent question of which innovation mode best characterises a country, which, in turn, facilitates the implementation of corresponding policy options.

Many data points and indicators are relevant to the creation of effective innovation policy. Rather than provide an exhaustive list, this report identifies four broad categories that are likely to be important for policy development. The four categories are: *Economic and Innovation Orientation, Energy Supply and Demand, Energy and Renewable Energy Policies, and Absorptive Capacity.*[1] An accurate national or sub-national analysis to elucidate which innovation mode best characterises a country's RET innovation stage requires assessing each of the following indicators, as described below:

Economic and Innovation Orientation

Economic and innovation orientation, and its associated indicators, provides a reasonable proxy of innovation capacities and gaps. Evidence suggests that historical and current economic activity strongly shapes future pathways for innovation (Hidalgo, Klinger, Barabasi, & Hausmann, 2007). Further, research suggests that export orientation provides strong clues as to national productivity measures (*e.g.* Mengistae & Pattillo, 2004; Wagner, 2007), and, as such, gives a reasonable indication of the current status of economic orientation.

1 In many ways, these categories mirror existing categorisations, such as Porter's Diamond Model (Porter, 1998), which includes four national categories: *factor competitiveness, context for rivalry, supporting industries* and *demand conditions.* The RETIP process provides an energy-centric interpretation of such models.

Innovation orientation, whether measured by percentage of GDP spent on R&D, or by more nuanced innovation rankings, such as those produced by INSEAD and WIPO (2012) and Bloomberg (2012), provide a broad and diverse set of criteria to measure and assess innovation capacities.

Energy Supply and Demand

Broad energy supply and demand trends shape the landscape of innovation. For example, the availability and relative cost of fossil and renewable resources impacts the prospects for RET deployment. In countries with ample coal, gas or oil, the incentives for RET deployment may be lower since domestic fossil resources represent a low-cost, readily available energy source, as well as a significant contributor to the local economy. The quality and geographic distribution of renewable energy resources also obviously have a strong impact on RET deployment in a given country or region. Nations with ample resources are endowed with comparative advantages relative to those with fewer resources. Nonetheless, countries with low levels of resources may participate in RET-based economic activity primarily through well-focused roles in RET supply chains and services.

Economic and energy demand trends also shape RET innovation opportunities. Rapidly expanding markets or areas with large unmet demand present attractive investment targets for both domestic and foreign firms. Slow-growth markets present different opportunities and challenges, mainly around replacing existing conventional energy generation with new renewable energy capacity. Accordingly, different sets of policies may be necessary.

Energy and Renewable Energy Policies

An assessment of current energy policies (both conventional and renewable-specific) is important to understand innovation opportunities. For example, fossil-energy subsidies, whether in the form of transportation fuel subsidies or price caps on fossil-based electricity, can strongly impact the business case for widespread RET deployment. Additionally, the presence of a national energy policy or a renewable energy master plan, whether it includes specific targets and incentives for RET deployment or not, is a strong indicator of innovation opportunities and barriers. Finally, existing energy R&D policies are important indicators of current innovation orientation.

Absorptive Capacity

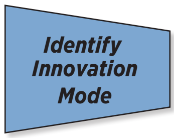
Absorptive capacity is an economy-wide measure of how easily new technologies, methods and business models can be assimilated. Absorptive capacity contributes, and is closely related to, well-functioning innovation systems. The main determinants of absorptive capacity include a range of factors, including: existing stocks of infrastructure, institutional capacity, human capital, training availability, financial markets and access to capital. Together, improving these factoral conditions can facilitate the absorption of RET innovation activities into the country's economy.

Insofar as absorptive capacity is a product of accumulated experience and investment across the economy, future absorptive capacity is a function of historical patterns. In other words, absorptive capacity is "path-dependent" and is impacted by patterns of technology "lock-in" (e.g. Unruh & Carrillo-Hermosilla, 2006). Indeed, global trade data suggest that an economy that has historically devoted significant investment in a certain product family may have difficulty absorbing the technologies and methods associated with a very different product family (Hidalgo *et al.*, 2007).

Renewable Energy Specific Absorptive Capacity

RE absorptive capacity is a sector-specific subset of general absorptive capacity that measures the ability to assimilate new renewable energy technologies, methods and business models. Absorptive capacity for renewable energy is largely a product of various technology-specific competencies (Walz & Marscheider-Weidemann, 2011). These conditions and competencies include: existing stocks of technology patents, trade volumes in a particular RET industry, stocks of sector-specific infrastructure, institutional capacity, tacit knowledge and human and financial capital. Some specific metrics of renewable energy absorptive capacity include: quality and extent of grid infrastructure, transparency of regulatory frameworks, power market structure, level of renewable-based generation as a percentage of total electricity generation, renewable energy labour skill levels and the level of entrepreneurship in renewable energy-related sectors.

2.2 RET Innovation Modes



Building from the above assessments, the concept of "Innovation Modes" provides a useful organising framework for the types of RET innovation activities that might be most relevant for a given nation or region. Innovation Modes combine the *context*-specific factors identified in a resource and capability assessment with the *technology*-specific requirements that define the landscape of RETs. In other words, Innovation Modes attempt to estimate the level of congruence between context and technology. Three RET Innovation Modes were introduced in the previous IRENA report (IRENA 2013): **Adaptation, Commercial Scale-up, and Technology Venturing**. These are briefly summarised below:

Adaptation

Adaptation encompasses efforts to introduce existing commercial technologies into new markets or localities. For example, deploying commercially available solar PV technologies on a remote Pacific island brings novel challenges that require innovation, albeit of a less scientific nature than a different type of innovation at the "technology frontier." Countries operating in this mode focus primarily on activities related to marketing innovative business models, customer engagement and social acceptance, and novel financing structures. While all countries exhibit some level of adaptive innovation, many developing countries operate *exclusively* in this mode, due to lack of financial resources, human capital and institutional support. Examples of this mode are employed in various rural states in India, Latin America and sub-Saharan Africa where policy efforts have supported energy-related micro-finance and other entrepreneurship efforts that attempt to bring existing RETs to new markets.

Commercial Scale-up

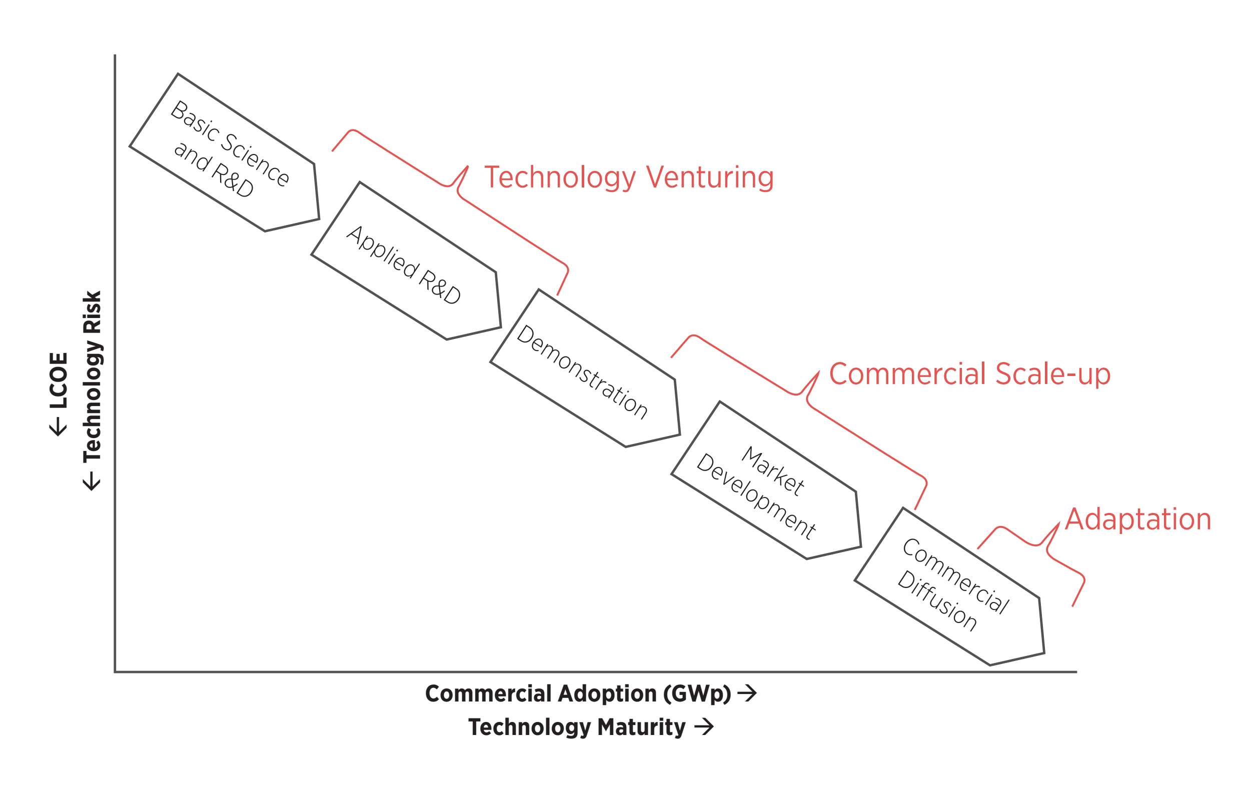
Commercial scale-up encompasses efforts to achieve broad commercial activity across the value chain of a technology – from manufacturing to retail deployment. In some cases, this pertains to moving a technology from the demonstration phase to commercial diffusion. This type of scale-up activity typically occurs after successful demonstration projects have been completed. In other cases, scale-up activities focus on building industrial capacity around proven technologies. These activities are pertinent for countries that aim to commercialise technologies that have already been fundamentally developed. Generally, countries operating in these modes do not have the capabilities to compete at the technology frontier. Instead of spending enormous amounts of resources on R&D to reach the frontier, these countries focus on incremental innovation activities. Examples of this mode are the strategies performed by some of the "BRIC" countries (*i.e.* **B**razil, **R**ussia, **I**ndia and **C**hina). Stakeholders that are relevant for this cluster include customers, suppliers, financial institutions and insurers.

Technology Venturing

This Mode is particular to a cluster of countries that 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 typically occurs in countries that are at the technology frontier, and often involves efforts to commercialise a breakthrough technology. In this technology mode, RET innovation involves the manufacture of novel systems, products or both and is typically highly research- and capital-intensive. Current examples include the efforts that Germany, the United States, China and others have committed during the last twelve years to increase technology and existing manufacturing expertise in solar PV panels and manufacturing systems. Because these activities require high levels of investment in technology and human capital, it is more frequent that *developed* countries exhibit characteristics of this Innovation Mode, although this distinction is becoming less sharp. Examples of the technologies of focus within this Innovation Mode are multi-junction PV cells, "third-generation" biofuel production systems, and utility-scale tidal power systems.

These three Modes can be conceived within a map of technology maturity (see Figure 4). Innovation Modes are not mutually exclusive – in fact most of the countries participating in Technology Venturing are simultaneously participating in Commercial Scale-up and Adaptation as well. As countries mature and deepen their innovation capacity, harbouring innovative activity along the entire spectrum of technology maturity, they become "full-spectrum" innovators.

Figure 4: Innovation Modes within the landscape of technology maturity

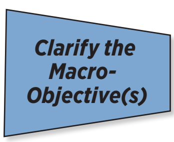


Source: IRENA 2013

In support of context-specific analysis, Table 1 illustrates the relationship between the resource and capacity assessment indicators outlined in Section 2.1 and Innovation Modes described in Section 2.2. Policy makers can adapt Table 1 to make a first approximation of the innovation mode that is most suitable, based on context, national objectives and technology focus.

Some of the data required to perform these assessments are available from existing international sources. Still others will likely require collection of local and context-specific data. Appendix A contains suggestions for some readily available data sources for many of the metrics above.

2.3 Clarify the Macro Objectives



Innovation policy takes place in a larger energy and economic policy context. Connecting innovation policy to "macro" policy objectives will result in broader stakeholder buy-in and more durable support. Thus the final step of the Assessment Stage is to evaluate the specific country-level differences that exist with regard to the macro goals of each country. As discussed in the case studies in Section 5, an alignment between macro country goals, energy objectives and RET innovation policy will better support long-term consistency and broad stakeholder buy-in. (Country-level macro energy objectives were widely discussed in IRENA (2013) and interested readers may refer to that report for a deeper explanation of each objective). Briefly, six macro energy objectives are commonly found alone or in combination in most countries: *Energy Security, Energy Access, Energy Cost, International Competitiveness, Modernisation,* and *Greenhouse Gas Reduction.*

1) *Energy Security* focuses on reducing dependence on vulnerable energy supplies.
2) *Energy Access* focuses on reducing energy poverty and expanding access to secure, reliable and low-cost energy.

Table 1: RET Resource Assessment Indicators in relation to Innovation Modes

Key Indicator	Data / Metrics	Estimated Importance to the Innovation Mode		
		Technology Venturing	Commercial Scale-up	Adaptation
Economic and Innovation Orientation	Global Innovation Index rankings; World Bank Governance Indicators, exports as % of GDP; clean Energy Patent Growth Index.	High	Moderate	Low
Energy Supply and Demand	Domestic energy consumption; energy imports and exports; level of energy access; domestic renewable energy resources; domestic fossil resources.	Moderate	Moderate	High
Energy and Renewable Energy Policies	Supply-side renewable energy incentives; energy R&D and demonstration support; fossil fuel subsidies; renewable energy targets.	High	Moderate	Moderate
Absorptive Capacity	Basic and advanced infrastructure; secondary and tertiary education rates; credit availability; intellectual property protection.	High	Moderate	Low-to-Moderate
Renewable Energy Absorptive Capacity	Clean energy patents and publications; RET trade volume; grid infrastructure; regulatory framework; power market structure; installed renewable energy capacity; renewable energy firms and entrepreneurship.	High	Moderate	Moderate
Example Countries		**Technology Frontier** (Denmark, Germany, Sweden, Japan)	**Emerging Frontier** (China, Brazil, India, Poland)	**All Countries** (Frontier + Emerging Frontier + Less Developed Countries)

Note: High, Moderate and Low are subjective terms used to indicate general levels of relevance. Example data sources can be found in Appendix A.

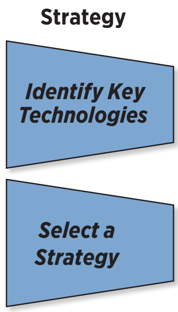
3) *Energy Cost* focuses on reducing exposure to persistently costly energy services.
4) *International Competitiveness* focuses on achieving greater competitiveness in international technology and service markets.
5) *Modernisation* focuses on rapidly modernising national energy systems to improve quality, reliability and efficiency.
6) *GHG emissions reduction* focuses on reducing GHGs and their impact on the environment.

RET innovation can support each of these objectives. Making direct linkages between RET innovation policies and these larger objectives will provide a broader basis for support.

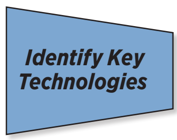
In summary, the Assessment Stage of the RETIP process focuses on a broad assessment of fundamental resources and capacities, identification of Innovation Mode, and identification of relevant national macro policy objectives. These "foundational" conditions comprise the landscape upon which other innovation policy planning activities can take place. Once these assessments have been considered, the path toward identifying innovation strategies and key technologies becomes clearer.

3 STRATEGY STAGE: IDENTIFYING KEY TECHNOLOGIES AND SELECTING INNOVATION STRATEGIES

This section builds upon the broad assessments above and briefly discusses narrowing the policy development "funnel" by identifying key technology sectors and selecting coherent innovation strategies.



3.1 Key Technologies and Sectors



Above, the concept of Innovation Modes was introduced in order to examine the level of congruence between technology-specific requirements and indigenous innovation capacities. This section pursues that relationship further. It is vital to identify particular technologies and sectors that best fit the contextual objectives and characteristics. In this regard, the RETIP process aims to clarify the landscape of considerations that can assist in the evaluation of competing technologies.

To select the most appropriate technology, decision makers must take into consideration the degree to which innovation activities will be driven by tapping *domestic renewable energy resources* versus *participation in regional and international trade*. These two domains are not mutually exclusive, but the relative balance has important implications for identifying key technologies and sectors.

The appropriate mix of domestic and international focus is a product of the various foundational assessments outlined in Section 2. The choice has consequences for policy strategy and resulting innovation types. For example, if domestic growth in renewable energy capacity is the driving force (*e.g.* driven by an *Energy Security* or *Energy Access* objective), then domestic renewable energy resources will be crucial determinants of appropriate industry sectors and corresponding policy strategies. The resulting deployment patterns of RETs will also drive industry activities and will shape the types of innovation capacity growth (for more on this topic, see, for example, Johnstone *et al.* 2010 and Walz *et al.* 2011).

In contrast, if participation in international supply chains is the driving force (*e.g.* under an *International Competitiveness* objective), then domestic renewable energy resources will be relatively less important, while any existing industrial and business capacities will be the crucial determinants of technology and policy strategies. Similarly, the resulting patterns of industry growth will produce distinct innovation capacity growth.

The case studies in Section 5 illustrate these approaches to selecting key technologies and also illustrate that both approaches can be pursued in tandem. For example, despite its limited solar resources, Germany was driven to become an international leader in the manufacturing of PV technology. It leveraged existing industrial and innovation capacity (together with strong financial incentives) to create a thriving solar-PV innovation ecosystem that gained significant global PV market share through the 1990s and 2000s. Twenty years later, also driven by its aim to goal become an international export power in PV technology, China implemented a package of policies that resulted in massive economies of scale in PV manufacturing. Similarly, Brazil's massive push for ethanol-based fuels in the 1970s was driven by acute energy security concerns, but was also facilitated by significant existing agricultural and processing expertise, an abundant natural resource endowment of fast-growing biomass and associated industrial capacities.

Thus, technology selection is driven as much by macro objectives and strategic considerations as it is by specific technology characteristics. Additionally, depending on the Innovation Mode, the most attractive link(s) of specific RET value chains will vary by country. For example, a country in the Adaptation mode with ample solar resources but low levels of innovation capacity may focus on the "retail" sectors of the solar value chain, such as final installation, maintenance, project development, etc., while a country in the Commercial Scale-up mode with the same resources might focus more heavily on the manufacturing sectors of the solar value chain.

3.2 Selection of an Innovation Strategy

Innovation policy portfolios benefit from an overarching theme that helps to provide strategic coherence. Since the development of strategic advantage and the search for strategic differentiation between regions is a key concept in innovation policy development, an organising theme for innovation policy can help provide differentiation amidst the broader forces of competition and globalisation. The companion IRENA 2013 report (IRENA 2013) describes in depth different strategies available for countries to foster the development of RET. A full survey of innovation strategies is beyond the scope of this report. Instead, three strategies are identified that reflect due consideration of Innovation Mode, and correspond roughly to those adopted by the case study countries outlined in Section 5. These are the *Open for Business* strategy, *Energy Security and Beyond* strategy, and *Innovation Clusters* strategy. Each is briefly described below and explored in more depth in the case studies.

"Open for Business" Strategy

This strategy seeks to invite foreign direct investment (FDI) in rapid renewable energy deployment and support for economic activities. Along the way, this strategy seeks to cultivate innovation capacity growth through workforce development (human capital), infrastructure development and firm-level partnerships (absorptive capacity). While also applicable to the Commercial Scale-up Mode, the case study of ***Chile*** is offered later in this report to illustrate how this strategy can be employed in the Adaptation Mode.

"Energy Security and Beyond" Strategy

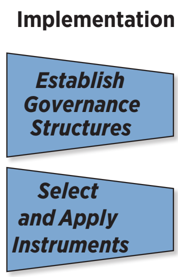
This strategy seeks to grow a domestic renewable energy innovation primarily to increase energy security, and then leverage that innovation to achieve other goals. Along the way, this strategy seeks to cultivate large networks of commercial activity, as well as some intermediate RD&D functionality. FDI can also play a role in this strategy. While relevant to all Innovation Modes, the case study of ***Brazil*** is offered to illustrate how it can be employed in the Commercial Scale-up mode.

"Innovation Clusters" Strategy

This strategy seeks to leverage existing innovation capacities to cultivate vibrant, diverse ecosystems of innovation – so called "clusters" – focusing on renewable energy technologies. The strategy employs a variety of policy tools, ranging from basic science to business incubation, involving a mix of national and local policy actors, as well as private firms and non-governmental organisations. While this strategy is also relevant to the Commercial Scale-up Mode, the case study of ***Germany*** is offered to illustrate its application in the Technology Venturing Mode.

These are certainly not the only RET innovation strategies. Others (*e.g.* focusing on rural energy entrepreneurship or large-scale industrial joint ventures) deserve attention and investigation but are beyond the scope of this report. The three strategies described here provide illustrative examples of coherent themes and a framework to view the case studies presented in Section 5.

4 IMPLEMENTATION STAGE: ESTABLISHING GOVERNANCE AND APPLYING POLICY INSTRUMENTS



Consideration can finally turn to designating appropriate roles and responsibilities for various governance actors and clarifying a coordinated portfolio of RET innovation policy instruments.

4.1 Establishing Governance Structures

This section explores some practical questions for navigating the issue of policy governance with the aim of delineating *who does what*. Governance roles and responsibilities are central to the implementation of RET innovation policy instruments and strongly shape the real-world application of the various policy options outlined in Appendix A. In this way, RET innovation strategies and governance are interlinked because government structure (*i.e.* the agencies and policy instruments ruling them) determines the feasibility of accomplishing local energy objectives. For example, the German model—namely, sub-national, cluster-based policy administered on a competitive basis by the federal government—may make sense in some political landscapes but not in others. Similarly, a network of centrally managed energy R&D laboratories may make sense in certain political settings but not in others.

Broadly speaking, governance decisions can be understood as having "vertical" and "horizontal" dimensions. The *vertical* dimension pertains to the level of decentralisation of policy. For example, national governments may set national renewable energy targets, or this power may be devolved to sub-national actors (*i.e.* states). The *horizontal* dimension pertains to the interactions between actors, both within government (*e.g.* coordination of various ministries), as well as externally (*e.g.* coordination with firms, academia and non-governmental organisations).

Coordination across these dimensions has been repeatedly recognised as a critical success factor.[2] Given the diversity of contexts and boundary conditions, there is general agreement that there is no single "good practice" of regional governance of innovation (Koschatzky & Kroll, 2009; Tödtling & Trippl, 2005). While important, the horizontal and vertical dimensions of governance add complexity to innovation policy design and management, and there is general agreement that managing innovation policy across boundaries is difficult (Tidd, Bessant and Pavitt 2005). Some specific considerations are discussed further, as well as other governance decision criteria, including interventionism and coordination costs.

"Vertical" considerations

The level of centralisation of political and economic resources also strongly impacts *who does what* in innovation policy. Amongst IRENA Members, significant variation exists with regard to the autonomy at sub-national policy levels and such considerations are relevant to RET innovation policy. Some specific decision-making criteria for devolving innovation policy to sub-national actors include the answers to the following questions:

- *Do the innovation activities benefit from proximity?* Certain innovation functions benefit from spatial and organisational proximity, such as support for start-up firms and existing small and medium enterprises, technology transfer from laboratories, links to universities and the management of technology centers and clusters.

2 Further discussion of governance and coordination issues can be found in Jacobsson & Lauber, 2006; Koschatzky & Kroll, 2009; Organisation for Economic Co-operation and Development, 2005; Smith, Stirling, & Berkhout, 2005).

- *Is there robust governance capacity at sub-national levels?* The presence of strong sub-national governments and actors and political trends promotes moves toward decentralisation and autonomy. This is especially relevant for early-stage technologies and is relevant for countries in the Technology Venturing mode considering policy interventions, such as catalysing high-tech clusters (Dohse, 2007). Additional relevant considerations regarding local governance capacity include:
  - Level of control and financing of secondary, post-secondary and vocational education;
  - Level of control and financing of science and technology research programmes;
  - Level of control of economic policy;
  - Level of control and financing of infrastructure;
  - Ability to set and enforce standards of various types (*e.g.* educational standards as well as grid-code standards);
  - Level of regulatory control of electric power utilities; and
  - Ability to create and enforce binding energy portfolio targets.
- *Is there strong demand for highly localised business-model solutions?* Strong demand for "end-of-pipe" innovation activities (*e.g.* financing and business model innovations necessary to bring RETs to market) typically lends itself to more active participation by sub-national actors (Koschatzky & Kroll, 2009). This may be due to various factors. Many countries have sharp differentials in regional renewable energy resources, such as the case of Chile, where northern regions are endowed with the strongest solar resources and may be better placed to craft effective policy. Additionally, many countries have sharp divides between urban and rural settings, which may alter the energy needs of consumers, and strongly impact the business model requirements for RET innovators. Education of consumers is essential in producing this sustainable demand.
- *Do local authorities and firms have better insight into labor market requirements?* In many settings, experience affirms the role of local authorities and/or firms as being the first to identify RET skills shortages (CEDEFOP, 2010). While national authorities play vital coordination roles and assist in applying formal methods for labour need estimates, effective communication with localities is critical. The fundamental difficulties of the labour anticipation-response cycle should be seen as a strong reason to focus policy efforts on decentralised, institutional agility, curricular modularity and strong public-private collaboration.

Finally, the "vertical" axis extends to supranational policy. Some options in this space include cooperative bi- or multi-lateral R&D agreements, participation in joint international innovation funding programmes (*e.g.*, the EU Framework Programme), technology transfer programmes through international mechanisms, such as the nascent Climate Technology Center and Network, or traditional donor aid funds for energy access. These distinct options may be appropriate for various countries. However, suggesting selection criteria for them in place of national or sub-national policy is beyond the scope of this report.

"Horizontal" considerations

Innovation policy always involves multiple agencies, ministries and external stakeholders and while the names and missions of the specific ministries will vary between countries, the relevant topical areas will commonly include energy, science and technology, education, economic development, finance, trade and immigration. Just how these ministries might need to work together will be strongly shaped by the Innovation Mode, macro energy goals and the given country's target technologies. The extent to which countries can accomplish energy objectives is strongly determined by the importance of this objective to the country's macro goals and the extent to which government bodies are accustomed to working in a coordinated way. Collaboration amongst stakeholders is important for innovation, and achieving collaboration at the horizontal level is vital to create coherence and avoid contradiction between policies.

The challenges of working across horizontal ministerial boundaries are evidenced in all three case study countries in Section 5. Some key considerations for horizontal policy governance include:

- *Level and type of research collaboration between government institutions and private firms.* In many cases where research and commercialisation is the goal, close collaboration between authorities responsible for economic, education and science and technology will be required (Koschatzky & Kroll, 2009). In Commercial Scale-up, this may take the form of coordinating between various ministries and major firms, such as the case of the Brazilian Instituto Agronimo, Bioethanol Science and Technology Laboratory (CTBE). In Technology Venturing cases, it may take the form of cooperative research and development activities between academia, national research institutes and private firms. Designing successful public-private partnerships is not a simple matter.

- *Coordination between energy regulators and relevant ministries*. Energy, worldwide, is a highly regulated industry. Efforts to support RET innovation can be neutralised by regulatory models that reinforce incumbent business models. For this reason, alignment between the regulatory authorities and innovation-relevant ministries is crucial. From a regulatory perspective, RET technology suffers from three distinct market-failures: R&D spillovers, environmental protection and access to monopolistic bottlenecks, all of which frustrate open and competitive markets (Walz, 2007). Thus, regulators play a particularly important role in the horizontal governance question.
- *Inter-ministerial coordination.* Coordinating between relevant ministries within the government can be challenging. For example, Ireland has struggled with two inter-related challenges in this domain – both cultivating the "right actors" within its national innovation system and enhancing the role of policy to achieve linkages between the elements of the entire national innovation system (Hilliard and Green, in OECD 2005). This issue was observed in Germany in the 1980s, where departmental conflicts were common and where efforts to expand wind energy were limited to relatively conservative subsidies, whereas subsidies for domestic German coal remained strong (Jacobsson & Lauber, 2006). Finally, effective governance efforts can, in some cases, be hampered by direct foreign aid that may frustrate coordination. For example, researchers have noted that Greece's governance capability to manage innovation, has been strongly shaped by external European Commission funding (Tsipouri and Papadakou in OECD 2005).

Other Governance Considerations

Beyond horizontal and vertical considerations, there are other important issues that impact governance. One is the posture or tendency of governments to engage in policy "intervention." Governments averse to interventionism may alternatively pursue a role more akin to "catalysis." The former entails direct control of significant elements of policy and economic activity by government actors. The latter entails a more *laissez-faire* approach with a focus on cultivating favourable legal and institutional environments, aiming to "stimulate but not govern" (Koschatzky & Kroll, 2009; Enright, 2003). Depending upon the context, innovation policy options will be limited by the posture of the given government in regard to interventionism.

A final consideration with regard to governance is the trade-off between autonomy and coordination. Both in terms of horizontal and vertical coordination, multi-actor and multi-level governance structures require significant attention to coordination (Dohse, 2007; Koschatzky & Kroll, 2009; IADB, 2007), activities which bring their own costs and complexities. If these costs are expected to be prohibitive, alternatives should be considered.

Various experiments are underway with regard to innovation governance. Some countries have established inter-ministerial working groups or councils to harmonise and coordinate innovation policy (*e.g.* Chile's InnovaChile, India's National Innovation Council, the European Union's Competitiveness and Innovation Programme, the U.S. ARPA-E and proposed Quadrennial Energy Review and Sweden's VINNOVA). The latitude and authority of these new structures range widely, as do their respective focus on energy matters. As such, the empirical success of these initiatives is indeterminate. The improvement of innovation policy governance is a critical arena for future work and international collaboration.

4.2 Applying RET Innovation Policy Instruments

Consideration now turns to the "option space" of policy instruments available to policy makers. This section provides a high-level discussion of RETIP instruments. A wider range of specific innovation policy instruments is discussed in Appendix A. As illustrated in Table 2, RET innovation policy options can be understood as belonging to seven functional categories, each pertaining to a potentially critical function for public policy.[3]

Within these categories, there exists a wide range of tools, some more applicable to certain Innovation Modes than others. Of the specific policies and strategies discussed below in this section, various examples are illustrated in Figure 5 plotted within the space of Innovation Modes. In-depth discussion of these instruments can be found in Appendix B and applied examples are discussed in the next section. The process of selecting instruments should also reflect the fact that feedback loops between different policies emerge, creating "virtuous" or "vicious" cycles and determining the system-wide dynamics of the policy strategy.

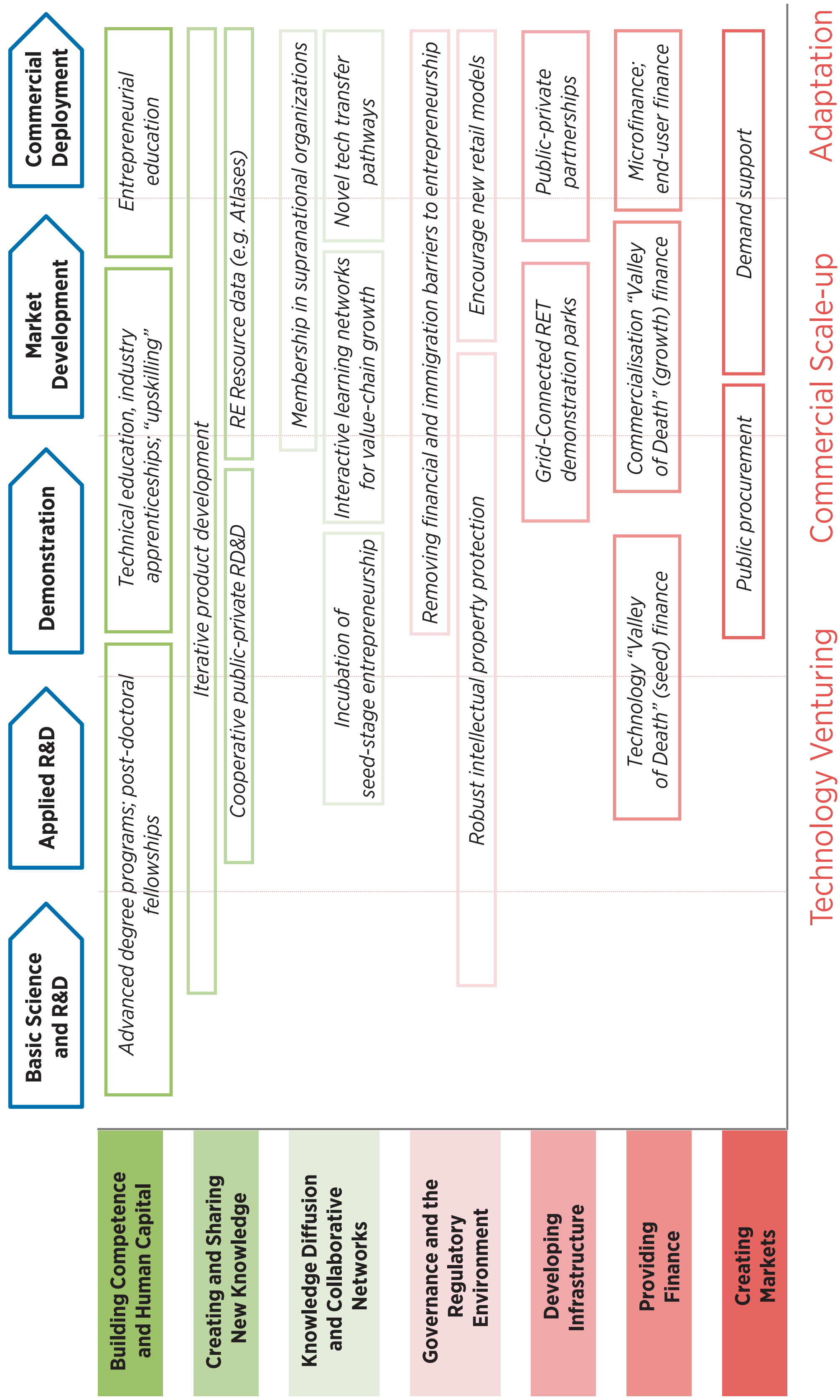
Table 2: Functional categories of RET innovation policy

Policy Function	Description
Building Competence and Human Capital	The development of human capital -- skills and competence --, either through academic or applied learning, is a basic and critical function for public policy.
Creating and Sharing New Knowledge	Development of platforms for the discovery and diffusion of knowledge, ranging from R&D to applied learning, accelerates innovation processes.
Supporting Knowledge Diffusion and Collaborative Networks	Networks support knowledge dissemination and business development that innovators need to be successful. Networks can be organised *inter alia* according to supply chains, geographic areas or industry sectors.
Establishing Governance and the Regulatory Environment	Innovation (and investment) is promoted by systems of rules, regulations and standards that are fair, clear, consistent and enforceable.
Developing Infrastructure	Energy technology requires significant infrastructure. Public policy can support investment in infrastructure that might not otherwise be built if left completely to private investment.
Providing Finance	Debt and equity capital promotes the diffusion of innovation, whether in the form of new products, processes or business models. Public sources of finance can complement private finance in supporting RET innovation.
Creating Markets	Supporting the creation of markets is a unique role for policymakers and is often crucial for providing stable conditions for the development of innovation ecosystems.

Source: Adapted from Tawney et al. 2011

3 These categories are adapted from a 2011 report from the World Resources Institute (Tawney, Almendra, Torres, & Weischer, 2011). Significant prior work on clean energy policy innovation suggested similar categorisations, especially Bergek *et al.* 2008, Bergek and Norman, 2008b, and Bergek, Hekkert and Jacobsson 2008c.

Figure 5: Example RET Innovation Policies mapped in the innovation landscape



5 NATIONAL CASE STUDIES: ORIGINS OF THE RETIP PROCESS

The RETIP process has historical roots, emerging out of the experiences of many countries as they have experimented with policies to support innovation. The preceding sections consolidate these lessons learned into a structured framework that can guide decision makers in navigating the many options for supporting RET innovation. As a way to provide further grounding for RETIP, this section examines the innovation processes of three countries in distinct milieux and timeframes Chile since 2008, Brazil from the 1970s to the present day, and Germany from the 1990s to the present day. These cases were chosen because their instructive experiences can benefit policy makers. They also illustrate how the RETIP process can provide a lens for understanding the policy development process, along the way illustrating specific innovation strategies that countries in each mode have adopted based on their country-specific circumstances. The three cases are selected to represent the three different innovation modes identified within RETIP: Adaptation (Chile), Commercial Scale-up (Brazil) and Technology Venturing (Germany).

5.1 Adaptation Strategy: Case Study Chile

Chile is provided as a case study in the Adaptation Mode of RET innovation. Given their impact on competitiveness, both energy and innovation are important policy themes in Chile and synergy between the two issues is an area of keen focus for policymakers.

Chile enjoys one of the most open economies in Latin America with significant levels of FDI. As with many developing economies, Chile relies significantly on the extraction of natural resources. These factors can be understood through the concept of the *"Open for Business"* strategy of RET innovation policy. Key features of this strategy include:

- Stable environment for entrepreneurship;
- Education incentives to enhance workforce skills;
- Immigration-friendly policies to attract foreigners aiming to invest or start a business;
- Strong focus on lower barriers-to-entry for clean energy business models;
- Government cost-sharing support for energy innovation activities; and
- Moderate demand-creation subsidies.

The remainder of this case study will discuss these strategies in the context of the RETIP process as articulated in the previous sections.

Assessing Resources

Innovation and Export Orientation

Chile ranks 39th out of 141 countries ranked in the Global Innovation Index (INSEAD/WIPO, 2012)—the highest in Latin America—yet it lags behind compared to other more developed economies in terms of innovation. In the World Economic Forum Competitiveness Report (2011-2012), Chile ranked 60th when assessing the investment of private companies in R&D. Whereas in most **OCED** countries 2.5% of GDP goes to R&D, Chile invests only in the order of 0.5% (Global Entrepreneurship Monitor Report, 2011). Less than five percent of Chilean companies are engaged in cooperative efforts with university research programmes and a 2013 survey of patents filed in the country (using the custom "INAPI-WIPO" database) revealed that Chilean residents filed only 13% of the patents, whereas non-residents filed the remaining 87% (Abud *et al.* 2013). Exports in Chile represent about one third of GDP, yet 75% of GDP is related to commodities, mainly copper, timber and fisheries products.

Energy supply and demand

In Chile 98.5% of the population has access to electricity (World Bank 2013). Chile has a current total generation capacity of 17,633 MW (Ministerio de Energia, 2012), with just over 640MW sourced from non-conventional renewable energy. Its instantaneous electricity peak demand for 2011 was 9,043 MW.

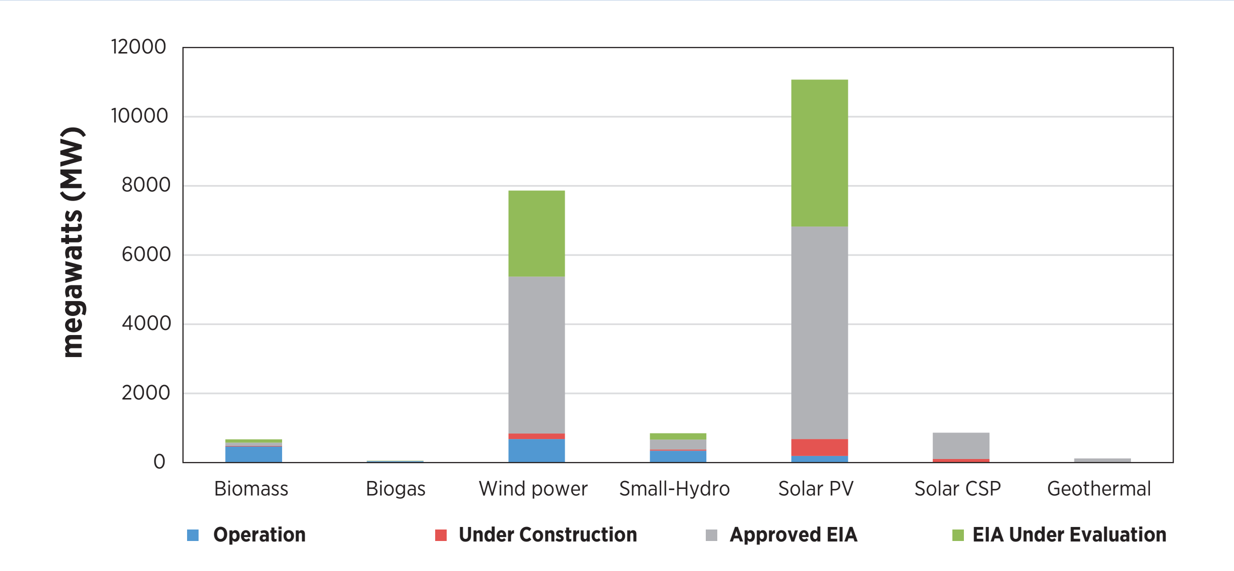
However, demand growth is expected to grow: the government forecasts an annual growth rate of 6-7% from 2011 to 2020[4]. To meet forecasted demand, the Chilean Government aims to increase the supply of both conventional and renewable sources of energy, the latter being domestically abundant. In contrast to renewables potential, Chile does *not* have significant hydrocarbon reserves. Accordingly, 80% of its oil, gas and coal are imported. Despite the fact that the National Energy Commission (CNE) determines electricity prices for energy distribution in Chile, the increased dependency on resources from other countries is reflected in the fact that energy prices in Chile are among the highest in Latin America, even higher than in many OECD countries.[5]

By 2012, 4.8%[6] of Chile's energy came from non-conventional renewable energy (comprising all RET with the exclusion of hydro plants with capacity greater than 20 MW), 34% from hydroelectric plants and 63% from thermoelectric plants fed with coal, gas and derivatives. Within the non-conventional renewable energy production, biomass plants produced 50%, followed by small hydro with 38% and 12% from wind energy. Solar PV produced only a negligible share. Since 2012 renewable energy has become more prevalent and many projects are now being reviewed, especially for onshore wind (see Figure 6). The supply of electricity, from renewable energy has more than doubled during 2011-2012, and global companies like Vestas[7] and Enel (among others) have started up operations in Chile.

Energy and renewable energy related policies

Chile was the first country in the world to liberalise its electricity market. As long ago as 1982 a law was passed separating generation, distribution and transmission components of the electricity industry. Today the national electricity system includes 31 generating companies, 5 transmission and 34 distribution firms, totaling 70 companies.[8] In the last decade, the Chilean Government has announced a series of measures to boost the adoption of renewables in the electricity sector. This effort started in 2008, with the establishment of a Renewable Policy Standard (RPS) goal of 10% by

Figure 6: Renewable energy capacity pipeline in Chile



Source: CER 2014

4 Estrategia Nacional de Energia, 2012: *www.minenergia.cl/estrategia-nacional-de-energia-2012.html*

5 Estrategia Nacional de Energia, 2012: *www.minenergia.cl/estrategia-nacional-de-energia-2012.html*

6 *http://cer.gob.cl/boletin/marzo2013/Reporte-20121.pdf*

7 *http://www.vestas.com/en/about-vestas/find-vestas.aspx?RegionID=12&CountryID=45&CountryCode=CL*

8 CNE – National Commission of Energy. Government of Chile. *http://www.cne.cl/*

2024. In 2012 the Chilean Government announced a new bill aiming to connect the two main transmission systems (SIC & SING), which represents an important step for the adoption of RETs, as this would allow greater sharing of renewable energy resources and reserve capacity.

General absorptive capacity

Chile's basic infrastructure is well developed: most of its roads are paved; the mobile phone penetration rate is extremely high (1.3 phones per inhabitant in 2011[9]). Chile's advanced infrastructure is also relatively sophisticated. Chile also has one of the most efficient financial markets in the world, which facilitates greater FDI. The government is concerned about improving local human capital by sponsoring an ambitious scholarship programme that aims send 20% of Chilean graduate students to study abroad.[10] The government is also committed to boosting the entrepreneurial environment by creating a programme to attract world-class early stage entrepreneurs and locate their start-ups in Chile. Finally, Chile is well known for its strong *institutional framework,* showing high levels of trust in the rule of law, and transparency of public governance mechanisms. This is true even if some cultural factors may continue to undermine competitiveness.

With regard to ***renewable energy absorptive capacity,*** the data suggest that Chile is in a nascent stage of absorptive capacity. For example, a survey of patents in RET areas indicates low levels of patent activity by Chilean scientists or businesses filed with the USPTO. As of 2008, Chilean inventors held only 14 patents in RETs. Also, at that time, value chain development in RET industries was fairly weak (ClimateScope 2013). Since then, the market for renewable energy deployment in Chile has grown significantly, and corresponding increases in value chains have improved overall renewable energy absorptive capacity. Renewable energy investment topped USD 2 billion in 2012, with over two-thirds of that going to wind projects (ClimateScope 2013). Until 2012, many key value chain segments for clean energy technologies and services were missing in Chile, but the country currently features a robust value chain for biomass and waste-to-energy projects, a small but growing service support for small hydro and wind projects, and some emerging value chain expertise for solar and geothermal projects (ClimateScope 2013). Table 3 illustrates these various aspects of the RETIP resource and capacity assessment.

9 http://data.worldbank.org/indicator/IT.CEL.SETS.P2

10 http://www.oecd-ilibrary.org/education/chile-s-international-scholarship-programme_9789264086425-en

Identifying the Innovation Mode

In light of the above assessment, Chile has the greatest potential to leverage the Adaptation Mode of innovation. Despite being ranked as one of the most innovative countries in Latin America, Chile is similar to other countries whose economy relies on exporting natural resources. Chile's energy demand is growing, and the country faces dilemmas in terms of where to obtain resources to produce energy surplus. Policies seem to support RET innovation, yet a lack of stability and mixed policy signals have created uncertainty in the energy sector. Chile's absorptive capacity seems to be on the right path, yet higher standards in education and workforce skills are still being developed to improve absorptive capacity at more sophisticated levels.

Clarifying the country's macro goals

Identifying the energy development goal(s) of a country is important because only a thorough understanding of the conditions and priorities of its government allows implementation of enduring RET innovation policies. *Global competitiveness* is the prevailing macro goal of the Chilean Government. Based on Chile's National Energy Strategy report 2012-2030[11], there are three goals that Chile is currently pursuing: *energy security, energy cost reduction* and *modernisation* as a means to address environmental concerns. *Energy security* is important because Chile has almost no fossil fuel reserves, so increasing its capacity to obtain electricity from local resources has become a national priority. *Energy cost reduction* is another priority. Since Chile relies on imports for about 80%[12] of its oil, gas and coal, the country is typically a price taker. As a consequence, the price of electricity in Chile is above the average price for OECD countries. Finally, *modernisation* and energy development are important because industrialisation and growing middle class of consumers with higher incomes increase the demand for energy. As part of its modernisation plan,

11 Estrategia Nacional de Energia, 2012: www.minenergia.cl/estrategia-nacional-de-energia-2012.html

12 Chile Energy Policy Review 2009. Paris: Organisation for Economic Co-operation and Development and the International Energy Agency, 2009. Print.

Table 3: RETIP resource and capacity assessment for Chile

Resource Assessment Indicators	Chile	Comment
Economic and Innovation Orientation	High export capacity, but concentrated in raw goods; moderate- to low-innovation capacity.	Relatively low level of high-tech exports and innovation provides examples for Adaptation and Commercial Scale-up contexts.
Energy Supply and Demand	Relatively small population; rapid growth; highly dependent on energy imports; abundant solar, biomass, geothermal and ocean energy resources; moderate wind resources.	Relatively low domestic consumption will constrain market size, provides lens for domestic Adaptation and participation in regional value-chains.
Energy and Renewable Energy Policies	Moderately ambitious renewable energy policies.	Policies provide some level of certainty for renewable energy growth, recommending a growing role for domestic entrepreneurs.
General Absorptive Capacity	Relatively well-developed absorptive capacities in basic domains; less developed capacities in high technology.	Absorptive capacity leadership in Latin America recommends efforts to stimulate business.
Renewable Energy Absorptive Capacity	Low-to-moderate levels of renewable energy absorptive capacity.	A key focal area of growth in Chile.

Chile aims to increase its deployment of local renewable resources to meet this growing demand.

Identifying key sectors and corresponding technologies

Achieving energy independence, cost reductions and modernisation are goals that go hand in hand with a strategy that aims to create openness for renewable energy businesses in Chile. In order to implement RET in Chile, an assessment of key sectors and corresponding technologies is needed.

Wind represents a promising match between resources and capacities. The Global Wind Energy Council estimates that Chile has 40GW of wind potential.[13] Since 2012, many wind projects have been approved and built. Over USD 1.3 billion was invested in Chilean wind projects in 2012. As a result, Chile has 205MW of wind energy and an additional 97MW were built during 2013. This growth has led to some improvements in technological competence at the national level, with wind blades and turbines now being produced domestically. Previously, the main value chain activities were in project development, engineering and operations (ClimateScope 2013).

Solar represents another potential match between resources and capacities. The northern part of the country is an arid region that hosts the driest deserts in the world, generating exceptional conditions for solar energy. According to the GENI (Global Energy Network Institute) 2011 report, Chile's desert has the highest irradiance in the world (275W/m2). High electricity demand due to intense mining activity suggests that fulfilling this demand locally would generate savings in transmission costs. Value chain strengths in the solar industry are focused almost entirely on its latter stages, such as project development and engineering (ClimateScope 2013). This key sector opens an opportunity for the Adaptation of solar PV technology in northern Chile.

Hydropower is also an abundant energy source, especially in the center and south of the country where the Andean mountain chain gets more snow. Currently, 34% of Chile's energy comes from hydro, however the target for 2020 is between 45% and 48%.[14] Today sixteen small hydro projects are being built, aiming to produce 114 MW. Technological competence in small hydro is relatively strong, with value chain activities, from turbines to project management to power plant operation already in place in Chile (ClimateScope 2013).

13 "Chile." Global Wind Energy Council (GWEC). *http://www.gwec.net/index.php?id=171*

14 Estrategia Nacional de Energia, 2012: *www.minenergia.cl/estrategia-nacional-de-energia-2012.html*

Selecting a strategy for the country: Chile "Open for Businesses"

Having assessed its strengths and weaknesses, Chile is pursuing an "Open for Business" RET innovation strategy. Understanding the importance of abundant renewable energy resources, stable institutional structure, ready grid interconnection as a fundamental prerequisite for the adoption of renewables, the Chilean Government has focused its efforts on one specific strategy: signaling openness for renewable energy businesses. Chile's traditional liberalisation policies, in addition to openness to international trade, have resulted in flexible and efficient markets.

Establishing a governance structure

In Chile, a National Council for Innovation and Competitiveness ("Consejo Nacional de Innovación para la Competitividad" or CNIC) was founded in 2005 and reports directly to the Chilean President. CNIC sets national innovation priorities across key industrial sectors. For implementation, CNIC relies primarily upon a public agency called the Chilean Economic Development Agency (CORFO; Corporación de Fomento de la Producción de Chile) that is part of the Ministry of Economy and serves to coordinate and implement productivity and innovation policies. CORFO works across various federal ministries (the horizontal dimension) and with the sub-national jurisdictions called "Regiones" (the vertical dimension). Federal ministries involved in innovation policy include *inter alia* the Ministries of Finance, Education, Economy, Development and Tourism, Energy, Mining and the Environment.

As the name CNIC—National Council for Innovation and Competitiveness—suggests, innovation in Chile is seen primarily as a means to enhance national competitiveness and increase productivity. That said, various governmental ministries have distinct priorities that require a level of coordination. For example, the Ministry of Energy has goals to enhance energy security, lower prices and increase sustainability. CORFO aims to bring stakeholders together from various ministries, private sector firms, and civil society organisations to find common ground and establish programmes that support a functioning innovation ecosystem.

Several changes are currently underway under a new presidential administration. In the period 2010-2014, coordination between federal ministries and with the regions was performed by a relatively small division of CORFO. With reforms underway, coordination is becoming a larger priority for CORFO. Additionally, prior to 2014, the innovation policy philosophy was to allow market forces to select the areas that should be supported. In other words, innovation support was equal for all industries. CORFO organised a single competitive process for innovation grants across many industries. As a result, proposals from diverse areas, such as medicine, energy and information technology, were all competing for the same funds. Today, a nascent process is underway to implement a concept of 'smart specialisation' (see OECD 2013 for more detail on this concept).

In Chile, the "smart specialisation" concept is viewed through the duel lens of matching industries to geographic zones. The key element of this concept is to support industries that are strategic for the development to the country. Three design questions help to guide the development of strategic innovation programmes:

- What makes sense at a national level (*e.g.* sustainable tourism across the whole country from Arica in the north to Punta Arenas in the south)?
- What makes sense at a territorial level (*e.g.* CSP and solar in three northern regions)?
- What makes sense at a regional level (*e.g.* bioenergy in the heavily forested 9th region)?

In practice, this approach means that, the next round of innovation grant programmes will be organised according to a smart specialisation framework, likely along these lines of national, territorial and regional levels. Currently, 30% of CORFO's budget is earmarked for strategic programmes, while 70% is generic to all industries.

Despite these recent changes in the management of Chilean innovation policy, some facets of innovation governance remain the same. ***First,*** innovation grants will still be distributed based on a competitive process through which research institutions and private sector partners are encouraged to formulate proposals. This competitive process helps to ensure that there is adequate interest and demand for the resulting innovation. ***Second,*** in the 70% of its funding reserved for generic support to all industries, CORFO will continue to focus its efforts on the pre-commercial stages of innovation—that is, through the prototype and demonstration stage, thus encouraging private risk capital to identify promising innovations for commercialisation. ***Third,*** for the 30% set aside for strategic programmes, additional support may be given to enhance the development of innovations that may already be more commercially mature. Formal diagnostic processes—with guidance from external advisors—will be in place to evaluate the merit and need of each proposing team. Finally, each strategic programme will be guided by a board composed of the distinct stakeholders, public and private, and coordinated by CORFO.

Applying policy instruments to facilitate implementation of RET innovation

In view of the above capabilities and constraints, Chile is pursuing a range of policies in most of the functional categories outlined in this report. A brief selection of these categories is presented below, along with challenges and opportunities for future policy:

Building Competence and Human Capital

Graduate degree programmes: Since 1981 the Chilean Government has funded a scholarship programme for Chileans to study abroad and bring back their knowledge to the country. In 2008, the quotas for this programme were increased.[15] Energy, environment, public policy, entrepreneurship and engineering are some of the government's priority areas. A better-prepared human capital asset will facilitate the adoption of the technology flows that Chile needs in order to achieve its energy development goals.

Knowledge Diffusion / Creating Collaborative Networks

International agreements with reputable supranational organisations: Chile has joined several international cooperation agreements. In 2010 Chile became the OECD's 31st member and the first country in South America under an accession agreement. The country has also signed more than 50 free trade agreements, encouraging international commerce. The main scientific branch of the government (CONICYT) has a number of support mechanisms to advance networking and knowledge transfer with other countries.

Open immigration policies and start-up incentives: CORFO promotes economic development through entrepreneurship and innovation. In 2008 CORFO funded a programme (*e.g.* Start-up Chile) to bring foreign entrepreneurs to Chile by facilitating their immigration process and funding their venture. Attracting skilled human capital and increasing local social capital are key activities for a country in the Adaptation mode to achieve its energy goals. Having an enabling environment that welcomes entrepreneurship and foreign companies is crucial to the process of adapting technologies developed elsewhere.

Attraction of international R&D investment and centres of excellence for competitiveness: The Ministry of Economy, Development and Tourism has defined the goal of converting Chile into a hub of innovation and entrepreneurship in the Latin American region as part of its strategy for economic development. For this purpose, it has implemented through CORFO programmes designed to attract entrepreneurs and R&D investment to Chile and to establish international R&D Centres of Excellence. These centres will carry out R&D, technology transfer and commercialisation activities in fields on the technological cutting edge, with high national and international economic impact (CORFO, 2014). Together, this package of strategies aims to strengthen national R&D and commercialisation capabilities in Chile.

Developing Infrastructure

Public-private partnerships: In Chile, public-private partnerships are a common mechanism for the development of basic infrastructure. Most of Chilean highways, for example, bear witness to this successful type of partnership. An open and competitive policy orientation has attracted international investors. Chile's "Electric Highway" project is an excellent example of how private international investors cooperate with public projects. Aiming to attract previously developed business models and technologies and adapt them to local circumstances, Chile has "jump-started" the process by inviting national and international developers to bid and participate in the construction of 500 kV transmission line connecting Chile's northern and central power grid. Chile's Electric Highway contributes to the achievement of national energy goals. This major grid integration scheme today stands as the country's premier innovation project.

Providing Finance

Clarifying Power Purchase Agreement (PPA) rules: In Chile, the novelty of the renewable energy sector makes it a somewhat risky place to invest. Additionally,

15 *http://www.oecd-ilibrary.org/education/chile-s-international-scholarship-programme_9789264086425-en*

the government has given mixed signals regarding support for the renewable energy sector; conflicting views between the judicial and executive branches of the Chilean Government are causing investors to think twice about proceeding with Chilean projects (Chadbourne & Parke 2012)[16]. Local banks are still cautious because there are no warranties about future prices and demand and there are still no long-term power purchase agreements (PPAs) that are a fundamental component of many financing schemes.[17] In summary, providing the conditions to increase financing of renewable energy projects in Chile is an ongoing challenge for its current government. A clear signal of the legal structure of PPAs, backed by strong national renewable energy targets, would resolve much of the financial uncertainty in the Chilean renewable energy sector.

Establishing Governance and the Regulatory Environment

Chile's governance structure has demonstrated positive changes since 2012 (Ministerio de Energía, 2012). New ministries are working in coordination with regional governance authorities to facilitate the deployment of RETs. However, there is still room for improvement, especially related to RET-specific regulations. Although subsidies and fiscal benefits to promote the adoption of renewable energy exist, there are still only limited benefits for the development of this sector. For example, small-scale renewable energy generators (smaller than 9MW) are excluded from the transmission toll, yet PPAs are not yet implemented, adding some risk to these projects. Improving the clarity of the signals provided by RET innovation policy is required for Chile to create a credible renewable energy market.

Creating Markets

Policies to support RET market growth have been discussed at length in Chile. From 2010 to 2013, negotiations took place on a bill to set a target of 25% for non-conventional renewable energy generation by 2025. In June 2013 the Chilean House of Representatives approved this bill and in September 2013 the Chilean Senate passed it (albeit with several modifications to the original text). This relative uncertainty has clouded the market in Chile, but the approval of the bill is likely to accelerate market formation.

16 *http://www.lexology.com/library/detail.aspx?g=77c5eaf7-3532-4a40-a143-ddae782aa54f*

17 *http://www.revistaei.cl/revistas/index_neo.php?id=1035*

The pathways described above are consolidated and illustrated in Figure 7.

In summary, Chile is currently focusing on building competence and human capital, contributing to knowledge diffusion and creating collaborative networks, and developing basic and advanced infrastructure. Challenges remain, including: augmenting the role for local governance where appropriate; providing more finance opportunities for energy projects; improving the regulatory environment; and creating a robust market to allow innovation capacity growth to flourish. Diverse policy tools and the support of international organisations and agencies are mechanisms that should help to accelerate the achievement of this goal.

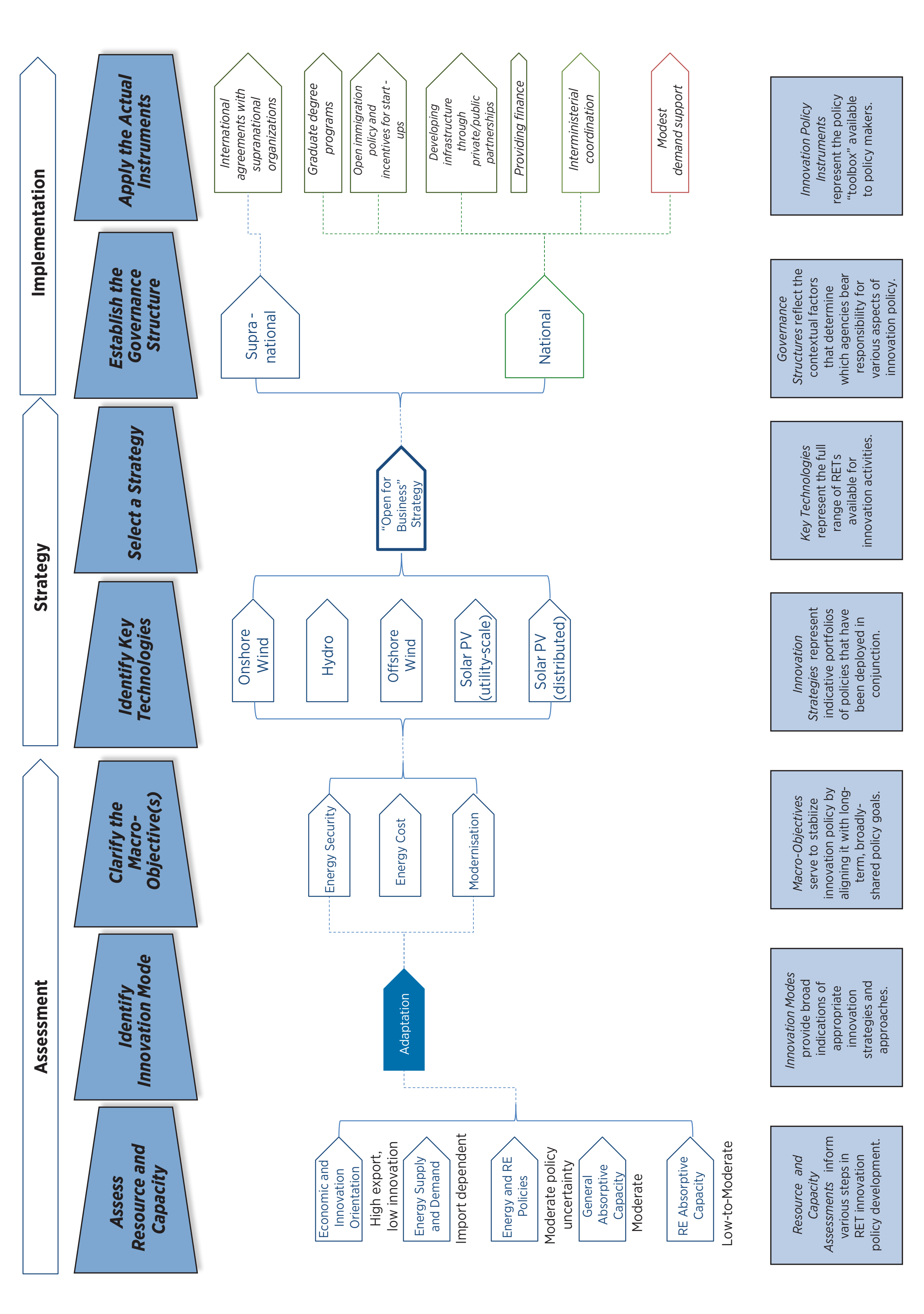
5.2 Commercial Scale up Strategy: Brazil

Since the mid-1970s, Brazil has built up a domestic ethanol production industry that has conferred substantial energy security benefits while growing into one of the largest global exporters of ethanol. This position of industry leadership did not emerge overnight. The cultivation of sugar cane—the sole source of Brazilian ethanol — has a 500-year history in the country (Galloway, 2005). Brazilian ethanol was first used in vehicles in 1925 and during the Second World War Brazil mixed 50% of ethanol into its gasoline. Leveraging this long history against the backdrop of growing energy security concerns in the 1970s, Brazil began to put policies and programmes in place that supported its emergence as a global export leader. This section briefly reviews this process of commercial scale-up through the lens of the RETIP process with a particular focus on how policies supported the development of a commodity biofuel industry hand-in-hand with a series of automotive innovations that created a market for it.

Given the energy security origins of its policies to support a commodity ethanol industry, Brazil is representative of an "Energy Security and Beyond" strategy that features the following approaches:

- Aggressive support for ethanol use, ethanol vehicles and R&D;
- Focused and sustained market intervention; and
- Strong focus on scientific, technical and industrial education.

Figure 7: Illustrative RETIP process analysis for Chile



Together, this case illustrates a wide range of innovation policy instruments working in unison. A brief accounting of Brazil's policy development drivers is presented below.

Assessing Resources

Innovation and Economic Orientation

Brazil ranks high in R&D spending, university-industry collaboration and quality of research institutions; yet it still lags behind in government procurement of advanced tech products, and in the availability of scientists and engineers. Today, Brazil ranks 58th out of 141 countries ranked in the Global Innovation Index (INSEAD/WIPO, 2012), second in Latin America after Chile. In the World Economic Forum Competitiveness Report (2012-2013) Brazil's innovation position was ranked as 49 out of 144 countries.

In terms of export orientation, despite its world-class export capability in ethanol, Brazil is not fundamentally positioned as an export economy. Its internal market is large and exports represented only approximately 13% of its GDP in 2012 (World Bank 2014).[18]

Energy supply and demand

Energy supply concerns played an important role in Brazilian innovation in ethanol. Due in large part to the first oil crisis and high dependency on oil imports, in 1975 the Brazilian Government implemented a programme—the National Alcohol Programme (NAP), commonly known as "ProAlcóol"—to produce ethanol from sugarcane, itself a resource that had been an economic engine for decades, as a gasoline substitute. The use of alcohol as a fuel was successful until 1990. Then shortages in ethanol supply, reduction in the price of oil and the elimination of tax benefits for ethanol-fueled cars drove the demand for pure ethanol cars down to almost zero in 1996.[19] However, by the year 2000 the situation started to reverse due to an increase in oil prices, a decrease in ethanol prices and the manufacture of flex-fuel vehicles. Being the world's second largest producer of ethanol after the United States, Brazil produced 22,721 million liters of ethanol in 2012, 96.4% of it consumed locally and 3.6% exported[20]. The demand for ethanol is expected to increase in future. The proportion of the Brazilian fleet of vehicles using ethanol was estimated at 27.7% in 2011; yet industry projections report that this share will reach over 80% by 2019.[21]

Energy and renewable energy related policies

As a result of high oil prices in the late 1970s, the Brazilian Government designed subsidies and policies that would boost the production of local energy sources. Industrial sector policies have promoted the replacement of oil products by hydropower, while transport sector policies have prompted the substitution of ethanol for gasoline. Policy has also focused on biofuels; minimum blending levels of ethanol and gasoline were revised in a 2010 mandate[22] requiring a minimum blending obligation of 25% volume, ensuring demand for this locally produced biofuel.

General absorptive capacity

Brazil's *basic infrastructure* over the 40-year timeframe of this case study has evolved from being relatively unsophisticated—roads, railroads and port infrastructure were basic, while transport infrastructure were in poor to moderate condition—to some of the best in Latin America.[23] Brazil's *advanced infrastructure* is of high quality, in part because the large size of the Brazilian market facilitates greater access to financing for investment projects. Additionally, an active financial sector and strong regulation of securities makes it an attractive destination for international investors. According to the World Economic Forum, Brazil still has room for improvement in the quality of its educational system to meet the increasing need for a skilled labor force.[24] According to current data, Brazilian firms and entrepreneurial companies report that procedures and timeframes required to start a new business remain among the best in the world. Taxation is perceived to be too high and to have distortionary effects. Brazil's *institutional framework* is fairly functional, but there is a general lack of trust in politicians and the efficiency of

18 http://data.worldbank.org/indicator/NE.EXP.GNFS.ZS

19 IADB, 2007

20 http://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Sao%20Paulo%20ATO_Brazil_8-21-2012.pdf

21 http://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Sao%20Paulo%20ATO_Brazil_8-21-2012.pdf

22 http://www.worldenergyoutlook.org/media/weowebsite/2012/WEO2012_Renewables.pdf

23 Construction of advanced infrastructure continues. Currently, two major pipelines are being built to bring ethanol to ports under Petrobras joint ventures.

24 World Economic Forum Competitiveness Report 2012-2013 http://www3.weforum.org/docs/WEF_GlobalCompetitiveness Report_2013-14.pdf

the government. The burden of regulation is high and portrays high costs for business and innovation.(ibid)

Renewable Energy absorptive capacity

Absorptive capacity in the sector of sugarcane-related industries is very high in Brazil. In addition to hundreds of years of sugarcane cultivation expertise, Brazil was also endowed with pre-existing experience in producing a range of cane-derived goods. Most mills can tailor output to produce sugar, ethanol and energy (heat and electricity) in response to prevailing market conditions. There are limits to this flexibility — a minimum output (*i.e.* about 25% of nominal capacity) of either sugar or ethanol from most mills must be maintained (Leal *et al.* 2013). In 2012 Brazil had about 440 sugar ethanol mills installed and its estimated production capacity for 2013 was about 42.8 billion liters. This estimate depends on yearly decisions made by individual plants to produce sugar or ethanol.[25] Electricity and heat produced by burning the bagasse (*i.e.* the biomass waste product remaining after cane processing) can also be exported to the grid. Pre-existing experience in these various energy outputs contributed to the absorptive capacity for new, innovative business models involving sugarcane.

In Brazil several local and international firms have engaged in the development of technology and equipment for ethanol. In addition to ethanol plants, a number of automotive producers also enhance Brazil's renewable energy absorptive capacity. Parts and systems suppliers, as well as car assemblers, are involved in the biofuels market, performing tests and research on biofuels use in vehicles.

Identifying Innovation Mode: Commercial Scale-up

Brazil is a country with a solid foundation for Commercial Scale-up. It has the fundamental ingredients to adapt technologies developed elsewhere, absorb knowledge and skills into local industry and transition to improved innovations based on local needs. Brazil's commercialising strategy has traditionally followed a path in which local markets are served first and global markets thereafter. However, maintaining leadership in global markets is an important next step that Brazil needs to take into account to remain a world leader in the ethanol industry. Other countries are investing in ethanol technology due to the attractiveness of the market.

In light of the above analysis, Table 4 briefly comments on the rationale for the Commercial Scale-up Innovation Mode for Brazil.

Clarifying Brazil's macro goals: Energy Security and International Competitiveness

Energy security has been an enduring goal for the Brazilian Government. Its large market and aggressive process of industrialisation and development are increasing its demand for energy. Furthermore, a series of relevant external events served as driving forces that made *energy security* Brazil's most important goal over the last forty years: the oil crises of the 1970's, severe droughts at the beginning of the 21st century and the unpredictability of oil prices have been important warnings that reshaped Brazil's energy priorities. *Global competitiveness* has also been another durable goal for Brazil, viewed as a key component to achieving economic development. Securing energy supply at reasonable prices and ensuring competitiveness at the global level are important goals that happen to converge in Brazil in a synergy with abundant biomass energy sources.

Identifying key sectors and corresponding technologies

While sugarcane and other forms of biomass are abundant, regional availability of energy sources differs across Brazil. The southeastern region is more industrialised and populated. Most oil refineries and gas production in the country are located in this area. The southern region is also rich in water reserves and has large areas of fertile land. São Paulo state dedicates about 65% of its cropland to sugarcane and is the cane growing center of Brazil. This state is also very well equipped with the right legislation, equipment, infrastructure and research centers and markets for the commercialisation of ethanol. All of these factors contribute to the identification of sugarcane-based ethanol as the key sector for innovation.

Brazil's Country Strategy: Energy Security and Beyond

Assessing its strengths and weaknesses, Brazil can be seen to have pursued an "Energy Security and Beyond"

25 *http://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Sao%20Paulo%20ATO_Brazil_8-21-2012.pdf*

Table 4: Resource and capability assessment for Brazil

Resource Assessment Indicators	Brazil	Comment
Economic and Innovation Orientation	High export capacity, local markets served first. Exports focused on commodities. Moderate innovation capacity.	Moderate level of high-tech exports and innovation recommends focus on changing its positioning and exporting knowledge, technology and expertise in the biofuels industry.
Energy Supply and Demand	Largest population in Latin America. Rapid growth. Rich in local energy sources. Demand for ethanol is forecast to continue growing in the next six years.	Relatively large size of the country population makes it interesting as a market; recommends broadening its focus and taking into account global markets.
Energy and Renewable Energy Policies	Ambitious renewable energy policies have been key in shaping ethanol's market development.	Policies provide some level of certainty of renewable energy growth; recommends diminishing regulatory burdens and strengthening institutions to attract international investors.
General Absorptive Capacity	Well-developed absorptive capacities in advanced domains, yet less developed capacities in basic infrastructure.	Absorptive capacity constraints in education and infrastructure require more attention.
Renewable Energy Absorptive Capacity	Advanced levels of renewable energy absorptive capacity in the ethanol industry.	Public-private agreements in the automobile industry have contributed to renewable energy absorptive capacities. Recommends maintaining these relationships.

RET innovation strategy. Understanding the critical importance of increasing its energy security and realising the potential of its abundant biomass resources and existing sugarcane industry, Brazil has focused on achieving fuel security with a mix of policies aimed at innovating fuel and vehicle technologies. The dividend from this programme of security-driven innovation has been a "competitive edge" in international ethanol markets.

Establishing a governance structure

In Brazil both federal and local governments have played an important role in the energy sector. The main federal actors around Brazil's ethanol industry are the Ministry of Agriculture, Farming Development, International Trade, Transport, Science and Technology, Education and Defense. Especially during the 1980s, 1990s and into the early 2000s, these various ministries worked in close cooperation to support the development of the ethanol market in Brazil.

For example, in the early 1980s, a national technical commission was established to coordinate the standards and industrialisation necessary for widespread ethanol vehicle deployment. This technical commission included the Ministry of Industry and Commerce, the National Council of Metrology, Standardisation and Industrial Quality, the Brazilian Association of Technical Standards and various automakers (Berger, 2010).

By the mid-1980s, the federal government created a multi-stakeholder working group to formally evaluate the "Pro-alcool" progress to date and articulate steps that could be taken to improve inter-ministerial coordination. This working group convened members of the National Commission of Alcohol, The Institute of Sugar and Alcohol, the National Oil Council, Petrobras, the secretariats of various state-owned companies and the Ministry of Finance (Berger, 2010). These stakeholders also helped set the targets, timeframes and policy frameworks to further another round of ethanol innovation (Horta, 2008).

State-level governance bodies also contributed to RET innovation policy. At this level, especially in the major ethanol producing states, such as São Paulo and Rio Grande do Norte, a variety of biofuels promotion programmes exist, particularly for the biodiesel and ethanol industry. Regional bodies have worked in promoting production, adoption and commercialisation of ethanol programmes by encouraging collaboration with universities and private companies. Perhaps the leading example is the São Paulo Research Foundation (FAPESP), which started operations in 1962, and is funded by the State of São Paulo through a levy of 1% of all state tax revenues. In 2012, FAPESP had a budget of 500 million USD and several thousand staff. FAPESP organises several major projects that reach vertically into federal ministries and horizontally into academia and private industry. For example, FAPESP produces the national scientific and technology roadmap for bioenergy in Brazil, funds research hubs in three state universities (*i.e.* USP, Unicamp, and Unesp) and hosts BIOEN, a long-term RD&D programme that connects with private companies on applied research and commercialisation programmes.

A common thread in the governance of Brazilian ethanol innovation policy has been the high degree of horizontal coordination between four strategic sectors—agriculture, industry, education and transportation—as well as the high degree of state-led policy development. Federal and state policy makers, through various coordinating mechanisms, accumulated a range of complementary achievements over the last thirty years that set the stage for ethanol innovation, including: funding for R&D, graduate fellowships for Brazilian students to obtain professional development in the biofuel sector, initiatives to standardise ethanol purity levels and funding to improve the quality of roads and research centers.

Applying policy instruments to facilitate implementation of RET innovation

The following is a brief selection of policy instruments that have been deployed in Brazil, organised by functional category:

Building Competence and Human Capital

Given the rural nature of sugar cane processing, a level of technical literacy is required on a national scale. Beginning in the 1970's, the Brazilian Government instituted a wide range of programmes to improve the educational baseline. One example of these broad-based programmes is FUNDESCOLA (launched 1998 and implemented in coordination with the Federal Ministry of Education), which aimed to improve the professional development of teachers across the country. In addition to baseline education and training, the Brazilian Government supports a portfolio of industry-specific technical training programmes for adults. For example:

- Technical and Vocational School Systems (SESI and SENAI) receive funds from industries to run courses tailored to ethanol markets;
- SENAR (National Service for Rural Apprenticeship) aims to develop rural occupational training systems; and
- SETEC and PLANFOR work with industry to develop short and inexpensive technical training courses for urban (and some rural) workers.

Creating and Sharing New Knowledge

Both federal and state governments fund biofuel and vehicle R&D programmes. For example, the state of São Paolo Biofuels Chamber promotes both R&D activities and large-scale financing of biofuels production ventures. Various federal R&D centers (*e.g.* the *National Laboratory of Science and Technology of Bioethanol* or "CTBE" and the *Brazilian Agricultural Research Corporation Agroenergy Programme* or "Embrapa Agroenergia") support over 100 scientists working in basic and applied biomass processing technologies. Private firms also collaboratively support ethanol R&D: *Centro de Tecnologia Canavieira* or "CTC"), a technology centre owned and operated by private firms, is the largest private ethanol R&D center in the world. Additionally, the *"Plano Conjunto BNDES-Finep de Apoio à Inovação Tecnológica Industrial dos Setores Sucroenergético e Sucroquímico"* or *PAISS,* programme, a joint effort of the Brazilian Innovation Agency (FINEP) and the Brazilian Development Bank (BNDES), coordinates the selection and funding of innovative business plans for advanced production and marketing methods for biomass processing.

In the field of vehicles, the federal Brazilian Government funded a research laboratory that helped establish the commercial feasibility of flex-fuel ethanol vehicles. This effort resulted in amplifying the internal market for Brazilian ethanol. Today, a system of tax incentives under the *Inovar-Auto* programme supports investments in automotive production and R&D in support of advanced flex-fuel vehicles.

Brazil also supports the creation of new knowledge through graduate and post-graduate degrees in advanced bio-ethanol processes. For example, the Inter-university Network for Sugar-Ethanol Development or "RIDESA" comprises seven federal universities that have signed an agreement to develop research for bio-fuels sector improvements. There are twelve "experimental stations" strategically located in states where sugar cane production is significant. Most studies are done at the graduate or PhD level with an emphasis on research related to the Sugarcane Genetic Improvement Programme (PMGCA).[26]

Knowledge Diffusion and Collaborative Networks

As indicated above, a wide variety of institutional arrangements are in place to support knowledge creation. Diffusion of this knowledge into the commercial sphere is also a focus of the Brazilian innovation system. At a policy level, private-public sector agreements have been important. For example, the Brazilian Government signed agreements with automobile manufacturers that led to large-scale manufacturing of ethanol-fuelled cars starting in 1981. Since 2003 the local automobile industry has developed and incorporated flexible technology, creating a stable market for ethanol in the transport sector. Similarly, incentives to support the use of ethanol in small airplanes have supported the commercialisation of ethanol technologies.[27] The *PAISS* programme mentioned above seeks to support the commercialisation of biomass processing technologies, in effect supporting the linkages between private firms and applied science within the Brazilian innovation ecosystem.

Governance and the Regulatory Environment

In terms of its "philosophy" and approach, Brazilian innovation policy governance has transitioned from extensive *intervention* to a more balanced approach of *intervention* and *catalysis*. Intervention has mainly come in the form of sustained ethanol fuel-blend mandates. In the early stages, the federal government directly managed ethanol pricing and economic activity. Only in the late 1990s did the Brazilian Government deregulate the price of ethanol. Some state governments have also played an important role, especially in education and R&D activities, as discussed in previous sections.

Providing Finance

The Brazilian Government has long provided a range of credit products for ethanol infrastructure investment. Until the 1970s sugar cane was exclusively used for the production of sugar, but the oil crisis opened an opportunity to build ethanol distilleries annexed to pre-existing sugar mills. Providing heavily subsidised loans at a low interest rates proved successful because it allowed landowners to finance capital investments that would provide flexibility in the use of sugar cane. In 2011 the Brazilian Government created credit lines with subsidised interest rates to support ethanol storage and the expansion of sugarcane cultivation.[28]

Creating Markets

Both federal and state governments have enacted an array of policies to create markets, including:

- **Guaranteed prices for ethanol**: During the 1980s and 1990s, the Brazilian Government regulated the relationship between producers and distributors to secure enough ethanol supply. Agência Nacional do Petróleo (ANP) requires fuel distributors to adopt a yearly supply contract structure to meet purchasing targets at warranted prices.
- **Tax incentives to stimulate demand for ethanol-fuelled vehicles:** Lower taxation on ethanol-fuelled cars activated the demand for ethanol-fuelled cars. These incentives were first implemented in the 1980s, eliminated in the 1990s and readopted in the 2000's.
- **Tax incentives for ethanol fuel:** Taxes for ethanol have been fixed constantly at a level that is lower than gasoline taxes, at both the federal and state level. This is another incentive that successfully activated the demand for ethanol-fuelled cars.
- **Ethanol use mandate:** While in 2011 the mandate for ethanol blended to gasoline decreased from 25% to 20%,[29] this mandate has provided stability and reliability to the demand for ethanol for about twenty years. The fuel mix is set by the government and reflects economic and production conditions.

26 A Blueprint for Green Energy in the Americas. Prepared for the IADB by Garten Rothkopf. 2007. Page 441. *http://www.gartenrothkopf.com/pdf/section_5.pdf pg 498.*

27 See *www.aeroneiva.com.br* for more information

28 See USDA Biofuels report for more information *http://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Sao%20Paulo%20ATO_Brazil_8-21-2012.pdf*

29 *http://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Sao%20Paulo%20ATO_Brazil_8-21-2012.pdf*

- **Regional producer subsidy:** Aiming to increase the supply of ethanol in the northern and north-eastern regions, during 2011 and 2012 the Brazilian Government offered a sugar cane subsidy to small farmers (*i.e.* those producing up to a maximum of 10,000 metric tons). This subsidy responds to balancing the cost of production differentials between mills in the central south and north of the country.

The pathways described above are consolidated and illustrated in Figure 8.

As this brief case study illustrates, energy security, economic development and energy innovation have progressed in unison in Brazil, supporting a complex regime of RET innovation policy. One key to the equation was the parallel development of ethanol alongside flex-fuel engine technology, unlocking an entirely new ecosystem of innovation and creating an immense market opportunity, not only domestically but also internationally.

5.3 Technology Venturing: Germany

This case study provides an example of Technology Venturing innovation policy through the historical lens of German RET innovation policies from the early 1990s to the early 2000s. Over this decade-long timeframe, Germany instituted a range of complementary policies at the national and sub-national levels that supported the development of fundamental innovations in solar PV cells and onshore wind turbines, as well as their subsequent migration from research centers to commercial application.

Thus, it is proposed that Germany is representative of an "Innovation Cluster" strategy that features the following approaches:

- Federal and state support for technology value chain development within and across regions;
- Aggressive, sustained demand-creation mechanisms at federal and state levels;
- Strong focus on research activities at the technology frontier; and
- Sustained support for demonstration and commercialisation programmes.

A stepwise examination of the origins of this innovation policy approach is presented below.[30]

Assessing Resources

Innovation and Export Orientation

Germany began the period under review with a strong financial and human capital resource base, featuring well-established firm networks producing finished manufactured goods and high-technology products for domestic and international markets. While international trade represented only 25% of GDP in 1990, cross-border trade channels were well-established and the European market promised relatively easy export access. Regional political and economic autonomy was relatively well-developed, as post World War II (WWII) reforms sought to ensure strong local governance at the "Länder" or state level to prohibit excessive concentration of federal power.

Energy supply and demand

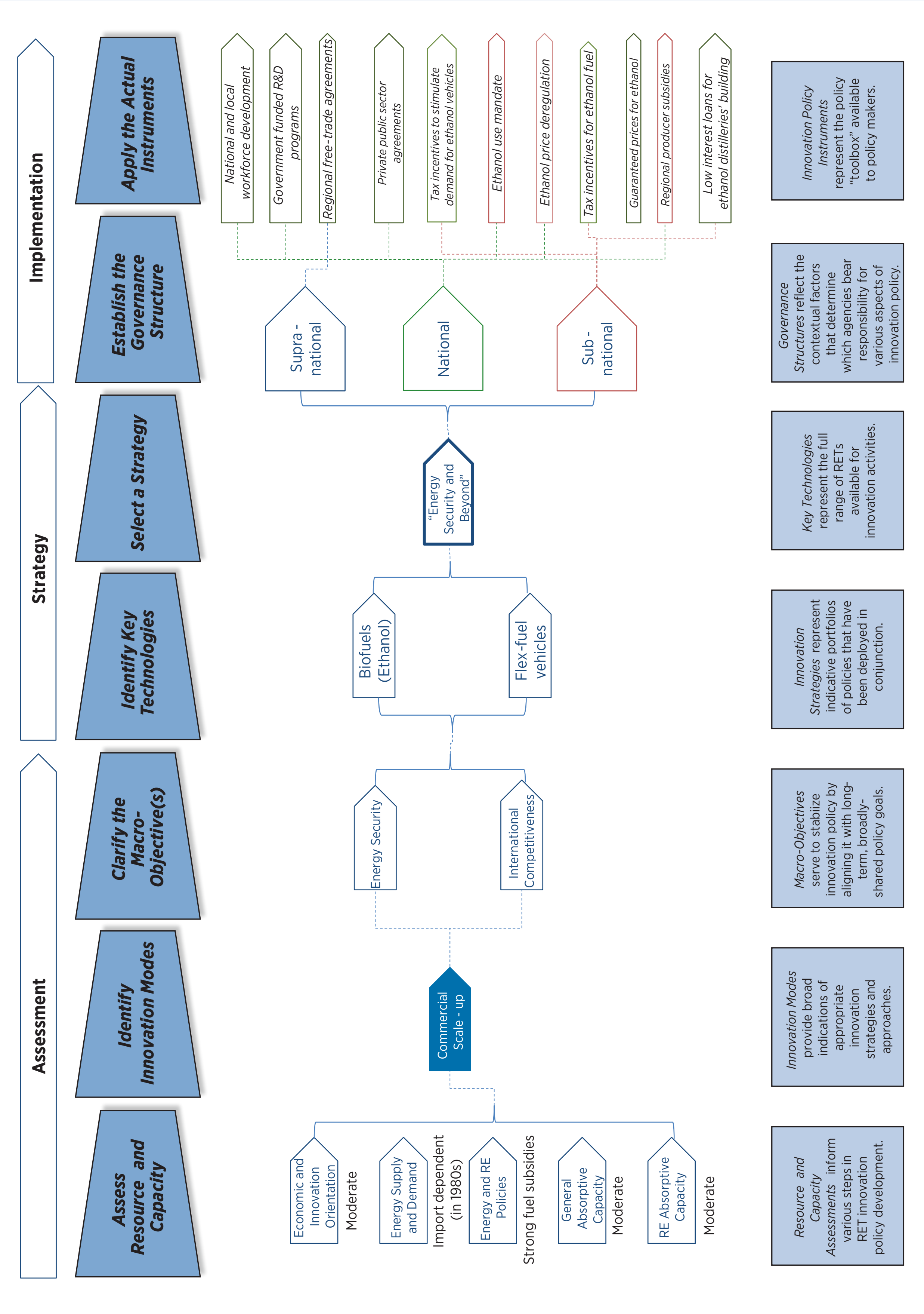
Electricity generation was primarily provided in the form of coal, nuclear and natural gas. While some coal was sourced domestically, its use was heavily subsidised by the German Federal Government at about EUR 4bn per annum in the early 1990s (Jacobsson & Lauber, 2006). Generally, Germany was dependent on significant coal imports and natural gas was sourced entirely from imports. Wind resources were plentiful while solar resources were moderate to poor. Nuclear power had provided a growing share of energy generation through the 1970s and 1980s.

Energy and renewable energy related policies

In the early stages of this case study, energy policy was crafted both to meet supply constraints and to support national industry development. For example, the energy crises of the 1970s resulted in policies to both insulate Germany from international supply volatility and to support domestic coal and nuclear production. As such, concerns over energy security, modernisation and competitiveness were drivers of energy policy reform. Over time, concerns over climate change rose to prominence in German energy policy. With broad support, legislative action was taken in 1990 to reduce

30 The time period of this case study includes the 1990 re-unification of East and West Germany. A full discussion of the economic issues of re-unification is beyond the scope of this report. In references prior to re-unification, "Germany" is used primarily to refer to West Germany.

Figure 8: Illustrative RETIP process analysis for Brazil



CO_2 emissions by 25-30% by 2005. In addition, the Chernobyl nuclear accident contributed to a strong shift toward renewable energy and energy efficiency, leading to a portfolio of incentives and R&D policies designed to favour emerging RET.

General absorptive capacity

By the late 1980s, strong regional agglomerations of German firms had emerged in various industries, such as aerospace, heavy machinery and analytical instrumentation. Labour productivity increased rapidly on an annual basis over the following decade. Education systems were robust, extending to graduate degree programmes in a wide range of engineering and professional domains. Infrastructure was highly developed, including a national electricity grid, increasing electricity integration with neighboring states across the study's time spectrum and a system of roads and railways unequalled in the world.

Renewable Energy absorptive capacity

Regulatory treatment of the energy sector proceeded erratically, in "fits and starts", finally promoting wind access to the grid in large quantities in the 1990s (and PV in the 2000s). With regard to wind and solar, Germany exhibited distinct absorptive capacity characteristics. Solar absorptive capacity was dominated by a wealth of basic science activities with relatively little patenting. The launch of the solar industry depended heavily upon existing complementary industries, such as silicon supply and machinery for semi-conductor processes. In contrast, wind absorptive capacity was less lab-based and more commercial, featuring a diverse ecosystem of mid-sized wind firms with significant patenting activity.

The early 1990s start-up time for this case study presents the general indicators of Innovation Mode in Germany as follows in Table 5:

Identifying the Innovation Mode

Germany's broad endowment of innovation and export capacities provides a unique lens for exploring the Technology Venturing mode of RET innovation. While Commercial Scale-up and Adaptation have been a significant part of the German RET experience, the early role of Technology Venturing is of most interest for this case study.

Clarifying Macro Objectives

A confluence of historical political trends provided durable momentum and direction to Germany's RET innovation policies. These can be understood through the lens of the macro objectives energy

Table 5: Early 1990s resource and capability assessment for Germany

Resource Assessment Indicators	Germany	Comment
Economic and Innovation Orientation	High export capacity, concentrated in finished goods. Moderate-to-High innovation capacity.	Predominance of high-tech exports and technology innovation recommends focus on Technology Venturing.
Energy Supply and Demand	Large population. Moderate growth. Highly dependent on energy imports. Abundant wind resources. Moderate to poor solar resources.	Large, import-dependent domestic markets (similar to most of Western Europe), recommends focus on domestic markets for value chain growth, then export orientation.
Energy and Renewable Energy Policies	Some domestic coal subsidies. Ambitious renewable energy policies starting in the 1990s. Little renewable energy policy uncertainty.	Strong renewable energy policies provide groundwork for commercialisation of innovations.
General Absorptive Capacity	Strong universities, many multinational firms, robustly developed industrial and financial value chains.	Strong general absorptive capacities recommend focus on high-technology ventures and export orientation.
Renewable Energy Absorptive Capacity	At the beginning of the period, renewable energy absorptive capacity was low, as all renewable energy technologies globally were nascent.	RE absorptive capacity growth was one of the dividends of the entire 1990-2004 period.

security, international competitiveness and greenhouse gas reduction.

Due to Germany's fundamental dependence on the import of fossil fuels, energy security represented—and continues to represent—a long-term national policy, providing ongoing incentives for energy innovation. International competitiveness is also a strategic national objective, especially for the manufacturing trades. Expanding the reach of German firms into new industries provides a complementary strategic objective that aligns with stable national goals. Greenhouse gas reduction has been a long-standing political objective in Germany, lending stability to innovation regimes.

Identifying key technologies and sectors

Wind and solar power were identified as promising sectors from the perspective of energy resources, especially in the wake of the 1986 Chernobyl nuclear accident (Molly 1999 as discussed in Bergek & Jacobsson, 2003). Solar power, while not an abundant resource domestically, represented an attractive technology based on the industrial profile of the German innovation system at the time (*e.g.* competency in high-quality chemical and materials finished goods). Wind power was, on the other hand, quite abundant, and also matched both the heavy-machinery and aerospace industrial competencies of Germany. For these reasons, wind and solar PV have represented the main focus of RET innovation activity in Germany.

Selecting a strategy: Innovation Clusters

In view of the above, the German strategy can be understood as an "Innovation Clusters" approach. This approach has a strong emphasis on sharing policy autonomy between the federal and state systems. It also cultivates diverse networks of actors beyond the basic R&D stages, extending into commercialisation, supply chain development and export-oriented firms.

Establishing governance

Innovation is viewed as a priority building block of the German economy, critical both to the economy as a whole but also to German energy transition. Innovation also plays an important role within German politics at both the federal and state levels (Jacobsson & Lauber, 2006). Germany has more than 800 publicly funded institutions, in addition to entrepreneurially-operated R&D centers. In 2011, the gross domestic expenditure on R&D was Euro 75.5 billion, with industry providing more than two-thirds of the research funding. Higher educational institutions accounted for 18% of this spending while almost 15% of total German R&D is invested by non-university research institutions (BMBF, 2012).

German governance is generally decentralised and innovation policy governance is no exception. Significant power is wielded at the sub-national levels. As such, substantial innovation policy efforts, especially with regard to demand creation and knowledge network development, have unfolded at the state ("Bundesländer") and local levels. Not only is innovation policy governance decentralised; regional technology clusters have also been a feature of German industrial development for decades, and so regional policy can draw upon existing networks from academia, the private sector and research institutes.

Horizontally, a variety of ministries were involved in energy and innovation policy at the German federal level, albeit not always consensually. These included the Federal Ministry of Environment, Nature Conservation and Nuclear Safety (BMU), Agriculture and Consumer Protection (BMELV), the Ministry of Economic Affairs (BMWi) and the Federal Ministry of Education and Research (BMBF).

Coordinating across these ministries, as well as with various stakeholders across the vertical and horizontal dimensions, is complex. In response, policy evolution in Germany has given rise to some specific institutional mechanisms that form pillars of the innovation ecosystem. Several of these are presented below.

The German Research *Projektträger* (Project Support)

One of the first consistent national approaches to innovation was implemented through the high-tech innovation programmes of the BMFT, which defined innovation priorities and consistently implemented programmes aimed at achieving faster results in product and market development. The sectoral focus of this programme included global challenges of health, climate, energy, mobility and security. The research and innovation activities of each programme were coordinated across multiple relevant ministries and across innovation stages through a novel organisational mechanism known as the Research *Projektträger* (project sponsor). In order to develop the existing structures in the direction of a continuously improved institutional design, this innovation structure remains open for the participation and consultation of all relevant stakeholder and experts (BMBF, 2014a).

Projektträger are professionally qualified facilities. The main task of the *Projektträger* is to support innovation project activities introduced by federal and state governments. They take the form either of official state-owned units (*e.g.* the "Research Center Jülich") or they are implemented by private companies acting in an official capacity for the government. For example, *Projektträger Jülich* coordinates research and funding innovation programmes in the field of energy amongst other domains, such as sustainability and environment and biotechnology. Commissioned by the German federal ministries and states, the *Projektträger* also advises on the national research and innovation funding programmes. In addition, *Projektträger Jülich* is a contact point to advise German applicants with respect to funding opportunities for research at an international level, such as the Seventh European Research Programme (Projektträger Jülich, 2014).

The German Research Foundation (DFG) is the German funding organisation for knowledge-oriented research on a myriad of topics. Self-governed, DFG selects projects on all topics with a view to ensuring the highest scientific quality through competition. Hence, fostering contacts between national and international researchers and scientists is an obligation included in the statutes of DFG. Provided that internationalisation is an essential requirement for Germany to become a pioneer and a hub for research and science, DFG funds international collaboration amongst researchers. Through its membership in various international committees and non-governmental organisations, DFG also plays an active role in international research policy (DFG, 2010).

Public Databases of Research Projects

Data on over 100,000 research projects are maintained in the publicly available databases of BMBF, including recently researched topics, projects that received public funding and the results delivered. Thus, the databases are a powerful source of information on Germany's research landscape and serve as a tool for networking within the science community. Similarly, the German Federal Environment Ministry issues a Technology Atlas that provides specific innovation-related information in the fields of renewable energy production and storage, and energy efficiency. These databases promote broad collaboration and knowledge sharing (BMBF, 2014b).

Renewable Energy Innovation Clusters at the State and Regional Levels

Bridging the gap between industry and scientific research is essential for the German Government's strategy, and regional cluster initiatives are a central mechanism to achieve this aim.

The partially (20%) state-funded Fraunhofer-Gesellschaft (or "Fraunhofer Society") conceives of and implements innovation clusters. The goals and milestones of the collaborative ventures are respectively self-set and defined. Local non-university research institutes which can make significant contributions in pertinent areas of relevance are included in the networks, in addition to industry and universities. The Fraunhofer Society stimulates the regional development of centers of excellence, skills and expertise through Innovation Clusters, some of which focus on renewable energy (Fraunhofer, 2014). Thus, innovation clusters serve primarily as an instrument to further develop existing strengths. The clusters can also motivate competitiveness within the markets of one particular technology, at the same time benefiting all involved in these fruitful collaborations. In particular, knowledge-based industries have facilitated the exchange of knowledge and generated a critical mass of skills to successfully complement one another in these regional clusters. Networks leading to new ideas for business and new enterprise foundations can be motivated by the geographical proximity between companies, investors and research organisations.

Lighthouse Projects

"Lighthouse Projects" are promoted and funded by different German ministries for specific projects related to innovation such as the IRENE ('Integration Regenerativer Energien und Elektromobilität', in English 'Integration of renewable energies and e-mobility') project, funded by the Ministry of Economic Affairs. This project involves better matching of electricity usage with renewable-based power generation. Funded by the German government, the project creates innovative solutions for a better use of the electricity generated from renewables by bringing together local utilities, industry, universities and other stakeholders, such as customers and municipalities (BMWi, 2013).

A significant structure emerges in Germany's innovation ecosystem, which can be evidenced by these institutional mechanisms. Across them all, intensive cooperation between industry and science is the *leitmotif*. The institutional programmes listed in this section (*i.e.* Research *Projektträger*, Lighthouse Projects and clusters), among others, facilitate cooperation between universities, research entities and industrial firms. This results in substantially lower barriers to technology and knowledge transfer from research centers and universities to industry. Finally, the governmental research funding also benefits from cooperation between industry and research entities.

Applying instruments

The following is a brief selection of policy instruments that have been deployed in Germany, organised by functional category:

Creating and Sharing New Knowledge
German federal authorities funded extensive R&D from the early stages of solar and wind development. As far back as the early 1980s, dozens of R&D projects were granted funding, both for industrial firms and academic institutes for the development of turbines from 10-400kW in size. Similarly, R&D funds to develop PV cells were disbursed to dozens of firms, universities and research institutes. These early programmes eventually expanded to include demonstration projects in the late 1980s. By the 1990s, wind power was "taking off," and active private firms increased their stake in R&D activities. It is estimated that from 1975 to 2002, wind power received approximately EUR 0.47 billion in government R&D funding while solar PV cells received EUR 1.15 billion (Jacobsson & Lauber, 2006).

Building Competence and Human Capital
Leveraging its endowment of excellent universities, German innovation investment has focused on a broad spectrum of human capital development. These include power engineering, aeronautics, chemical and materials science, and other wind- and PV-related university courses. More recently, specialised training programmes have been established to ensure an adequate labour pool. Much of this emerges from a well-developed and applied educational platform – the Dual Education System – that combines classroom-based and on-the-job training over a period of two to three years specifically geared to meet industry needs.

Knowledge Diffusion / Creation of Collaborative Networks
Clusters and collaborative networks are a signature German innovation policy. Whether by intentional design or due to historical agglomeration, regional networks of firms, universities and research institutes have comprised the core of much of the solar (and wind) industry. State-level policies were established in the 1990s to indirectly support regional RET supply chain development (Bergek & Jacobsson, 2003), such as requirements for locally produced wind turbine content.

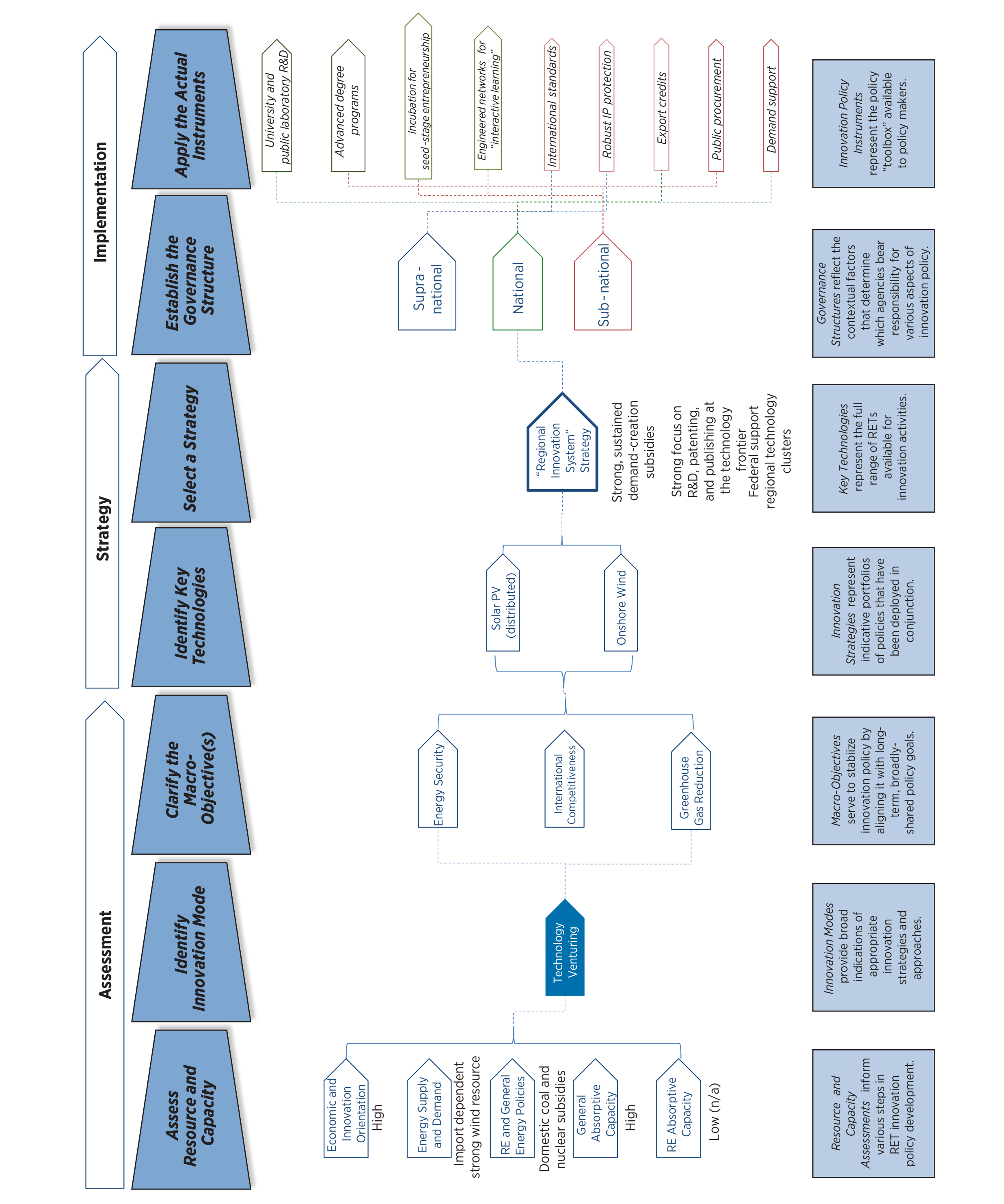
Providing Finance
Demonstration finance to prove that wind and solar technologies were viable was an early focus of Germany's federal policy. The main mechanism is discussed below in "Creating Markets" (*i.e.* a range of feed-in tariffs that have served to provide revenue certainty to investors and firms). Various states provided financing for local content (*e.g.* the Nordrhein-Westphalen programme of 50% investment support exclusively for turbines from the local firm Tacke (Tacke 2000 as discussed in Bergek & Jacobsson, 2003). In addition to these demand-side mechanisms, Germany also liberally deployed export credit assistance to support domestic enterprises' activities in international markets (Lewis & Wiser, 2007). Additionally, for early wind energy projects, federal sources provided loans below market rates (Lewis & Wiser, 2007).

Creating Markets
Both German federal and state authorities enacted various market support mechanisms. In the 1990s, the federal 100/250 MW wind programme (which aimed to increase total installed wind capacity by a factor of ten) and the 1,000 solar roofs programme, provided critical financial support to jump-start markets. State-level public procurement programmes were set up such that local utilities would subsidise solar installations on public buildings, such as schools. Throughout the 1990s, the combination of state subsidies and the federal Electricity Feed-in Law (enacted in 1991) gave considerable financial incentives to install wind electricity, which was more economical at the time. A subsequent law, the Renewable Energy Sources Act, passed in 2000, set in motion the major domestic installation of solar

PV capacity. This stable and diverse array of market support mechanisms, and the subsequent capacity additions, have moved Germany into the top ranks of total installed capacity in both technologies. The pathways described above are consolidated and illustrated in Figure 9 below.

As this brief case study illustrates, a confluence of external factors, historical competencies and targeted policies aligned at the end of the 20th century to give rise to dramatic growth in the industrial and innovation capacity of German firms in the solar PV and wind sectors.

Figure 9: Illustrative RETIP process analysis for Germany



6 CONCLUDING OBSERVATIONS

The case studies above illustrate selected historical precedents for the RETIP process and, along the way, demonstrate a wide range of RET innovation opportunities and corresponding policy approaches. In each case, unique strategies have emerged, driven by the contextual variables at work in different settings. The RETIP process provides a lens through which these varied national development can be viewed through a common framework.

IRENA Members can use the RETIP process as a basic guide to design appropriate RET innovation strategies. The three stages outlined herein provide a platform for structuring the policy development process. When applied in national contexts, this framework can strengthen national policies in the following ways:

- **Encouraging a holistic view.** The RETIP process brings together several key domains that are typically viewed in isolation: economic factor endowments, energy resource assessments, institutional capacity assessments and renewable energy technology and value chain characteristics, to name but a few. Together, these domains provide an appropriately comprehensive view of the variables that impact innovation policy design.
- **Encouraging innovation outside the laboratory.** While some innovation policy frameworks focus on conventional metrics of innovation (*e.g.* patents, start-up companies, venture capital), the RETIP process emphasises the routine and retail nature of much of RET's important innovation. In this way, the full IRENA membership is encouraged to evaluate their opportunities for RET innovation.
- **Encouraging a focus on enabling conditions.** While some innovation policy frameworks dwell primarily on the innovation opportunities within a specific renewable energy technology, or solely on the energy policy landscape, the RETIP process places technology characteristics within the larger context of enabling conditions. This acknowledgment—namely, that innovation cannot be *forced,* but rather must be *enabled*—will drive long-term decision-making and thus, hopefully, better outcomes.
- **Encouraging a focus on governance.** Policy is only as good as the institutions tasked with its implementation. The RETIP process helps to clarify the limitations and constraints that often frustrate innovation policy development and implementation. Keeping capacity and coordination constraints in view during the RET innovation policy development process will result in more realistic and achievable policy goals.

Beyond strengthening innovation policy, the RETIP process can, in addition, help to clarify areas in which IRENA can assist countries—upon their request—to employ these assessment methods, identify appropriate strategies and key sectors, design coordinated policy portfolios, and define implementation roles and responsibilities. IRENA, through its Innovation and Technology Centre (IITC), can assist in the completion of the RETIP process in support of sub-national, national or regional policy development processes.

RET innovation policy represents a unique opportunity, both to achieve national and local economic development and to promote global benefits. The development of cooperative approaches to RET innovation policy development through peer learning and applied research will further improve RET policy frameworks and deployment outcomes.

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APPENDIX A:

Candidate Data Sources for Innovation Mode Assessment

Key Indicator	Indicator Metrics and Candidate Sources of Assessment Data
Economic and Innovation Orientation	**Global Innovation Index rankings:** INSEAD and the World Intellectual Property Organization (2012) *http://www.globalinnovationindex.org/gii/* **Governance Indicators:** World Bank Governance Indicators (2013): *http://data.worldbank.org/data-catalog/worldwide-governance-indicators* **Exports as a percentage of GDP:** World Bank data: *Exports of goods and services (% of GDP)* (2012) *http://data.worldbank.org/indicator/NE.EXP.GNFS.ZS*
Energy Supply and Demand	**Domestic energy consumption:** US Energy Information Administration (2013) *http://www.eia.gov/countries/data.cfm* International Energy Agency (2013) *http://www.iea.org/stats/index.asp* **Energy imports and exports:** US Energy Information Administration (2013) *http://www.eia.gov/countries/data.cfm* International Energy Agency (2013) *http://www.iea.org/stats/index.asp* **Level of energy access:** IEA World Energy Outlook Energy Access database (2012) *http://www.worldenergyoutlook.org/resources/energydevelopment/globalstatusofmodernenergyaccess/* **Domestic** renewable energy **resources:** IRENA Global Atlas for Solar & Wind (2013) *http://www.irena.org/globalatlas/* Local, high resolution assessments, if available **Domestic fossil resources:** World Energy Council (2008) *http://www.worldenergy.org/data/resources/* Local, high resolution assessments, if available
Energy and Renewable Energy Policies	**Supply-side** renewable energy **incentives:** IEA World Energy Outlook 2012 subsidy database (2012) *http://www.worldenergyoutlook.org/resources/energysubsidies/* IEA / IRENA Policies & Measures Database (2012) *http://www.iea.org/policiesandmeasures/renewableenergy/* **Energy R&D and Demonstration support:** IEA / IRENA Policies & Measures Database (2012) *http://www.iea.org/policiesandmeasures/renewableenergy/* **Fossil fuel subsidies:** OECD Inventory of Estimated Budgetary Support and Tax Expenditures for Fossil Fuels (2013) *http://www.oecd.org/site/tadffss/* IEA World Energy Outlook 2012 subsidy database (2012) *http://www.worldenergyoutlook.org/resources/energysubsidies/* **RE targets:** REN21 Global Status Report (2012) *http://new.ren21.net/REN21Activities/GlobalStatusReport.aspx*

Key Indicator	Indicator Metrics and Candidate Sources of Assessment Data
Absorptive Capacity	**Basic and Advanced Infrastructure:** National and Subnational data sources **Secondary and Tertiary Education Rates:** World Bank data on Education *http://data.worldbank.org/topic/education* Supplemented by local data **Credit availability:** World Bank data: Domestic credit to private sector (% of GDP) *http://data.worldbank.org/indicator/FS.AST.PRVT.GD.ZS* **Intellectual Property protection:** World Intellectual Property Organization *World Intellectual Property Indicators 2010* *http://www.wipo.int/export/sites/www/freepublications/en/intproperty/941/wipo_pub_941_2010.pdf*
Renewable Energy Absorptive Capacity	**Clean Energy Patents:** WIPO Climate Change / Energy Patent Landscape (2013) *http://www.wipo.int/patentscope/en/programs/patent_landscapes/published_reports.html#climate_change* Heslin Rothenberg Farley & Mesiti P.C. *Clean Energy Patent Growth Index* (2012) (USPTO only) *http://cepgi.typepad.com/heslin_rothenberg_farley_/* **Clean Grid infrastructure:** Data from national and subnational grid operators. **Value-Chain Development:** ClimateScope (2013) (for Latin America only) *http://www5.iadb.org/mif/climatescope/2013/* **Regulatory framework and Power market structure:** Local and national data sources **Installed** renewable energy **capacity:** International Energy Agency (2013) *http://www.iea.org/stats/index.asp* REN21 Global Status Report (2012) *http://new.ren21.net/REN21Activities/GlobalStatusReport.aspx* **RE firms and entrepreneurship:** Local and national data sources

APPENDIX B:

The Landscape of Innovation Policy Instruments

Building Competence and Human Capital

The development of human capital—skills and competence—, either through academic or applied learning, is a basic and critical function for public policy. Some general and mode-specific policy approaches (*e.g.* education, market development and investment) are discussed in this Appendix.

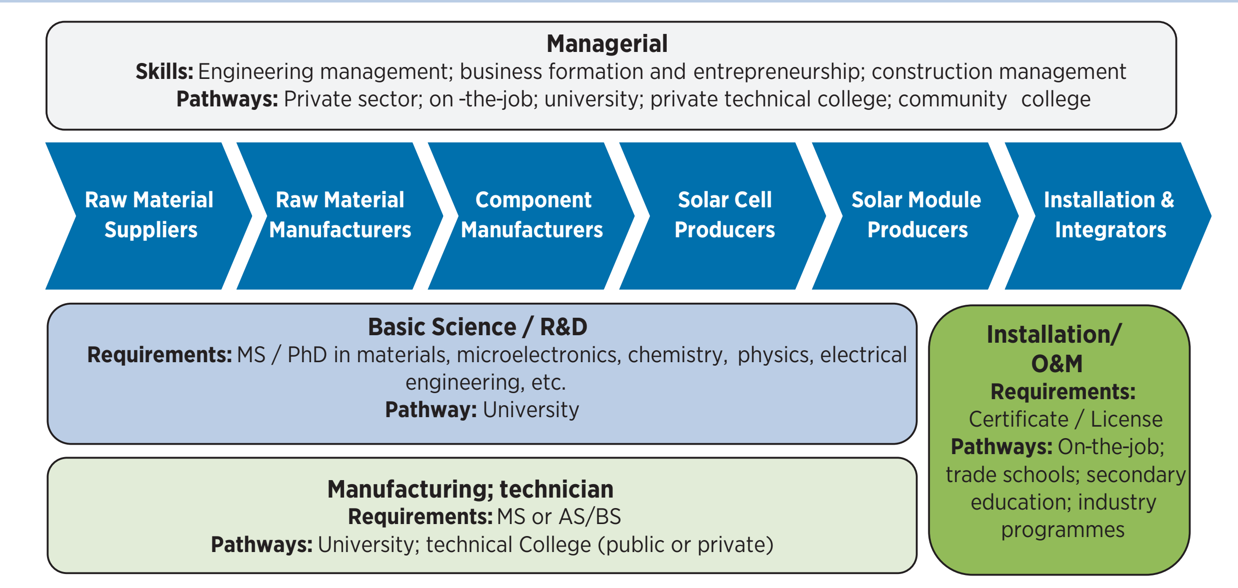
General approaches: *Education and Labour Force Development*

Innovation in all modes is enabled by successful educational and labour force development systems. The requirements of such systems are sensitive to the technological characteristics of various RETs, the scale and trajectory of RET markets and the landscape of the domestic deployment context. Together, the constellation of strategies and policies in this domain impact innovation capacity insofar as networks of experience and expertise give rise to incremental (and radical) innovations in products and processes.

To illustrate the role that education plays in promoting these networks, Figure 10 illustrates a simplified range of competencies associated with a single RET value chain—solar PV. These range from highly skilled PhD-level scientists to entrepreneurs and managers, to roofers and other construction trade persons. These competences can be delineated as follows into four broad occupational categories, each with unique skill requirements, educational pathways and relevance to countries operating in different Innovation Modes:

- Basic Science and Research & Development (R&D);
- Manufacturing;
- Installation and Operations & Maintenance (O&M); and
- Management (across all three domains above).

Figure 10: Illustrative occupational categories for the solar PV value chain



Source: Author analysis

Labour force development is crosscutting insofar as all innovation activities (regardless of mode) require ample skilled candidates for firms to hire.[31] Supply for the various roles of an RET value chain is largely determined by educational capacity, adjacent industry maturity and immigration policy. For example, in the PV solar domain, supply for skilled lab labour is constrained by the graduation rates of domestic universities, the existing pool of labour in adjacent industries (*e.g.* semi-conductors and telecom), and skilled-immigration policies. Furthermore, the supply of highly-skilled engineers and PhDs is typically clustered near technology agglomeration centres (Almeida & Kogut, 1999).

One example of upstream education is the Brazilian Government's support for a portfolio of industry-specific technical training programmes to support ample skilled workers for the ethanol industry. These range from technical and vocational courses tailored to ethanol markets to rural apprenticeship training systems to short and inexpensive training courses for urban (and some rural) workers (IADB, 2007).

At the retail end of the spectrum, solar PV system installation is a 'hybrid' occupation: the foundational skills are shared with other electrical and construction trades, while complementary solar skill sets (and, in some cases, certification and licensing) are distinguishing features. Similarly, micro-hydro also has labour force requirements at the retail stage. Given the mainly utility-scale nature of wind, geothermal and conventional hydro, there is less need (and opportunity) for retail labor force development and consequently less opportunity for substantial skill overlap with conventional trades. Pathways into a given workforce (*e.g.* solar installation), can include 'up-skilling' existing construction workers, continuing education for the temporarily unemployed construction labour force and vocational training for new installers. Sources of education include public and private vocational schools, on-the-job training and union-sponsored training.

These synergies and workforce requirements will vary by RET, and the strategies relevant to a particular country will be highly sensitive to its context, but the general importance of workforce considerations cuts across all technologies and Innovation Modes.

Education in the Adaptation Mode: Entrepreneurial Education

Relative to developed countries with long-established incumbent electricity providers, many Adaptation settings are endowed with a relatively fluid and dynamic business environment. In this setting, policy efforts to promote effective entrepreneurship can be uniquely important. Training efforts are widespread, and in Adaptation settings where *energy access* is the main objective, training is in many cases coordinated with micro-finance institutions to improve the success rate of lending efforts. Notable exemplars of such training efforts are "Barefoot Power" in Kenya and Uganda, Solar Aid in various East African nations and Servals and NEST in India (Bardouille, 2012). In other cases, entrepreneurship training is performed in coordination with universities, such as the collaboration between Ghanaian solar home system provider Deng and the Nkrumah University of Science and Technology (ibid).

Education in the Commercial Scale-up Mode: *Targeted Labor Market Support*

For policy makers aiming to initiate or sustain a period of Commercial Scale-up, labour market factors can strongly impact the ability to start and grow local firms, to rapidly scale-up manufacturing capacity and to compete in global trade networks. In this regard, anticipating and responding to labour market needs is a critical function for the Commercial Scale-up Mode and implies an intensive focus on public-private stakeholder collaboration.

Lessons learned from Europe can inform the strategies of countries in the Commercial Scale-up mode. A 2010 survey of "green" workforce development programmes in a selection of (mostly western) European countries revealed that most countries have well-established programmes of labour market anticipation that guide workforce development planning (CEDEFOP, 2010). The existing frameworks typically combine quantitative forecasting, qualitative needs assessments and formal and informal dialogue with education and training providers (ibid, p. 29). For example, France operates a national network of labor forecasting "observatories" that survey various regional or sectoral players in the

31 The interplay between increasing education and increasing skilled immigration is an important policy consideration but lies beyond the scope of this report.

labour market, combining these qualitative results with macro-economic projections and quantitative surveys (ibid, p. 88). France, Germany, Denmark and the UK in particular have an established history of anticipating and responding to environmental labour needs, relying on their existing systems of 'green' labour anticipation to guide solar workforce development planning (ibid, p 21). Even in Spain, where there is a less established national system for anticipating environmental labour needs, strong local and regional systems compensate (ibid.)

Creating and Sharing New Knowledge

Development of platforms for the discovery and diffusion of knowledge, ranging from R&D to applied learning, accelerates innovation processes. Some general and mode-specific policy approaches are presented below.

General approaches: *Iterative Product Development*

Innovation, especially of the incremental sort, is promoted by strategies that cultivate feedback between users and technology developers (Mowery & Rosenberg, 1979), leading to the demonstration of technologies outside of laboratory settings and subsequent learning-by-doing. The importance of robust feedback loops has been noted across the various stages of technology maturity. In the Adaptation domain, especially in contexts with an energy access goal, integrating RET innovations into daily life requires experimentation and trial-and-error (Kline & Rosenberg, 1986). These iterative cycles help close gaps between the needs (and financial resources) of poor users and dominant energy technologies and are crucial to adoption, technology credibility and market growth (Bardouille, 2012). An iterative innovation ecosystem is illustrated earlier in the report, in Figure 1.

The importance of user feedback to technology developers has also been noted in relation to earlier innovation processes (especially Commercial Scale-up and, to some extent, Technology Venturing). This has been evidenced in the divergent commercial success of American and Danish wind companies (Garud & Karnøe, 2003). In this example, the Danish innovation system featured a much more tightly linked network of technology developers, owners and intermediaries, while the US system was marked by isolated laboratory research aimed at "breakthroughs", which may have contributed to the relatively small-scale wind turbine manufacturing sector in the United States.

These lessons suggest the importance of policy strategies to cultivate networks of feedback. In this light, strategies that isolate innovation activities behind laboratory walls carry greater risks than strategies that promote extensive customer and stakeholder engagement.

Creating New Knowledge in the Technology Venturing and Commercial Scale-up Modes: Targeted Research, Development and Demonstration (RD&D)

Targeted investments in RD&D – typically involving academia, laboratories and, in later stages, industry—is a foundational knowledge development component of Technology Venturing and Commercial Scale-up. RD&D produces fundamental improvements to products and processes and public policy plays an important role in supporting it, since investment tends to be sub-optimal due to market failures, such as knowledge spillovers. Recent advances have focused on improving the co-ordination and cost-effectiveness of linkages between public and private actors, and across governance areas. For example, across the European Union, the European Research Area now administers a number of coordinated innovation investment activities that span public research institutes and private industry (*e.g.* the Framework Programmes, European Research Council, the Competitiveness and Innovation Framework Programme and the European Institute for Innovation and Technology). These activities aim to increase the interaction between research and commercialisation activities. Similarly, in the United States, the Advanced Research Projects Agency for Energy (ARPA-E) aims to commercialise innovative RETs developed in university and national energy laboratories and, if approved, a proposed "Quadrennial Energy Review" would serve to better organise energy R&D funding across multiple agencies.

Creating and Sharing New Knowledge in the Commercial Scale-up and Adaptation Modes: *Renewable Resource Data and Atlases*

With a priority on growth in renewable-based generation capacity, creating and sharing knowledge of the geographic location of renewable energy resources is an important arena for public policy. High-quality renewable energy resources are more economical to tap first, whether wind, solar, hydro, geothermal or some other renewable energy resource. In this light, resource assessment and prospecting will be an important enabler of RET innovation and deployment. Promoting enhancements to these capacities will be a key role for policy. In many cases, national efforts in this domain can now be supported by supra-national organisations such as IRENA.

Knowledge Diffusion and Collaborative Networks

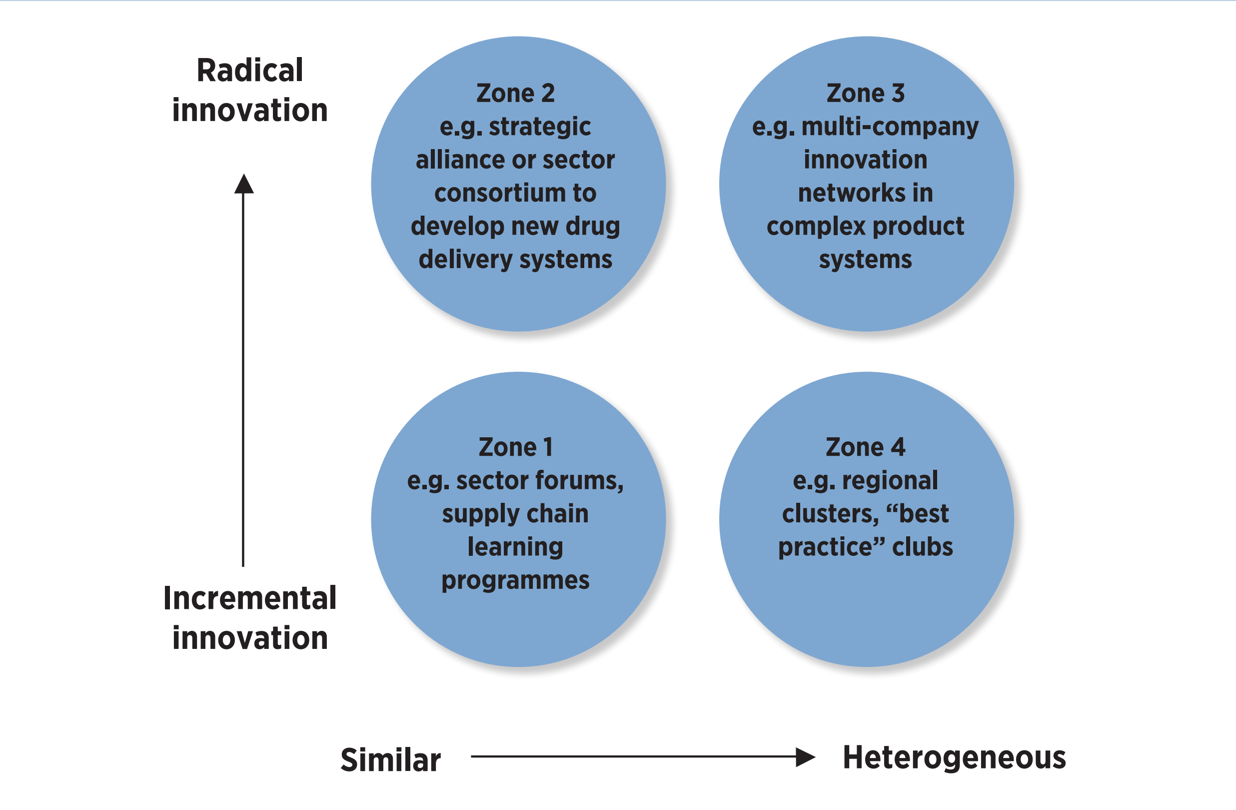
Robust networks support knowledge dissemination and business development that innovators need in order to be successful. Networks can be organised according to *inter alia* supply chains, geographic areas or industry sectors. Some general and mode-specific policy approaches are presented in this section.

General approaches: *Engineered Networks*

Engineered networks are deliberate attempts to support accelerated innovation by constructing networks of actors. Engineered networks historically have been organised either by geography or by technology value chains. Examples of this strategy include clusters, industry consortia or "supply chain learning programmes" (Tidd, 2006). The common feature of these strategies is that they all acknowledge the importance of communication and knowledge spillover between various actors within the innovation ecosystem.

An illustration of the various types of engineered networks appears in Figure 11. In this conceptualisation (Tidd, 2006), the types of engineered networks can be organised along two axes: how *radical* the desired innovation and how *diverse* the stakeholder firms. Accordingly, the types of goals of engineered networks may be quite tactical and determinate, for example, focusing on enhancing supply chain learning

Figure 11: Types of "engineered" innovation networks



Source: Adapted from Tidd 2006

or establishing technology standards. Alternately, the goals of engineered networks may be more creative and risky, for example high value innovation networks.

Less structured approaches have also emerged for organising engineered networks, for example:

- Brokerage and exploration of "weak tie" networks in which remotely connected actors may produce significant breakthroughs (Lee Fleming, Mingo, & Chen, 2007; Tidd, 2006).
- "Open innovation" ecosystems in which firms lower conventional barriers to collaboration and explore ideas across networks of non-firm actors (Chesbrough, 2003; L. Fleming & Waguespack, 2007; Malone & Klein, 2007).

These models may be country-customised in each of the Innovation Modes. In light of the varying needs, and with these new loose models emerging, it is important to recognise that engineered networks require sustained, effective management. These management requirements are highly sensitive to the composition of the network, the maturity of the technology in question (which, in turn, impacts issues of information sharing and intellectual property protection that are intensified near the "technology frontier"), and network diversity. Researchers of engineered networks encourage caution, noting that, for each successful governmental intervention to cultivate an entrepreneurial region, there are dozens of failed attempts (Lerner, 2009).

Knowledge Diffusion in the Adaptation Mode: *Leveraging Novel Technology Transfer Pathways*

Novel technology transfer pathways are likely to be most important in Adaptation settings, especially with regard to energy access. The energy technology innovation systems that have emerged in OECD countries may not meet the needs of customers in emerging economies. In some ways, energy system innovations from other developing economies may be more appropriate. While North-South technology transfer has been the predominant model for RET transfer under climate regimes, South-South partnerships may do more to facilitate technology transfer that more readily matches the unique economic, cultural and geographic concerns of consumers in the Adaptation Mode. In this level of fit, South-South transfer pathways may do more to enhance innovation capacity (Tawney, Miller & Bazilian, 2013).

Knowledge Diffusion in the Commercial Scale-up Mode: *Interactive Learning*

"Interactive learning" refers to a technology transfer process in which partners increase their fundamental competence during applied innovative processes. This type of knowledge diffusion was first identified by Lundvall (1988), and was analyzed in connection with the Danish and Indian wind turbine industries by Kristinsson & Rao (2008). Interactive learning is typically promoted by face-to-face interaction, often between technology frontier firm operating with a local partner in an emerging market, in which both parties benefit from regular interaction. In other cases, supply chain partners learn from each other, gaining not only efficiencies but also deepening competence in the process. Policy to promote supply chain networks and local joint ventures involving leading international firms can support interactive learning opportunities.

Knowledge Diffusion in Technology Venturing Mode: *Start-up Incubation*

Incubation of start-up companies is knowledge diffusion and collaborative networking strategy for the Technology Venturing Mode. Various sub-national units around the world have established programmes to incubate RET start-up companies. Israel provides some lessons for this type of activity. In concert with the cultivation of risk capital, a public/private Incubator Programme[32] was established both to organise R&D efforts, as well as to incubate new companies. At least three incubators focus mainly on environmental technology transfer from major Israeli universities (*i.e.* Ben Gurion University, Technion and the Weizmann Institute).[33] International collaboration also plays a role: the US-Israeli Bi-national Industrial R&D Foundation has been leveraging government funds to provide cost-share R&D grants in various high-tech sectors for more than 30 years. This programme added a "cleantech" grant programme in 2008 in conjunction with the US Department of Energy.

32 See *http://www.incubators.org.il/*

33 See "Cleantech Incubators Thrive in Israel." *http://www.ventureitch.com/?p=486*

Governance and the Regulatory Environment

Innovation (and investment) is promoted by systems of rules, regulations and standards that are intended to be fair, clear, consistent and enforceable. Some mode-specific policy approaches are presented below.

Regulation and Governance in the Commercial Scale-up and Adaptation Modes: Standards and Quality Certification

Well-developed quality standards are an important mechanism to establish the credibility of renewable energy technologies (Lewis & Wiser, 2007). Establishing credible national standards, or acceding to international standards, can strongly support the marketability of a firm's products and to accelerate progress along technology learning curves for new manufacturers. Supra-national support for renewable energy standards is now an area of joint focus between IRENA and the United Nations Industrial Development Organization (UNIDO).

Regulation in the Adaptation Mode: *Supporting New Retail Models*

The regulatory environment in which retail energy business models evolves is critical. The Adaptation Mode is marked by a need for regulation that encourages business model innovation in dynamic, user-centered environments. For example, regulatory treatment of mini-utilities is critical for their long-term financial viability (Bardouille, 2012). Such treatment must be coordinated with efforts to encourage grid extension by incumbent utilities, as the two goals can be at odds. Some support for retail business model innovation may be warranted in cases where energy access is the driving priority, or in contexts where retail deregulation is a policy objective.

Regulation and Governance in the Commercial Scale-up and Technology Venturing Modes: Removing Financial Barriers to Entrepreneurial Risk-taking

Risk-taking is, *a priori*, essential for RET. Some percentage of new ventures will fail and if the real (or perceived) risks of failure are too great, entrepreneurship will be stifled (Parker, 2004). In many countries, bankruptcy carries immense financial and societal risk. Entrepreneurship may be encouraged by reducing the personal financial risk of bankruptcy, for example through limited liability incorporation, which protects personal assets from creditors. Such legal and regulatory structures are most likely to be vital in the large-scale entrepreneurship required in the Commercial Scale-up and Technology Venturing modes.

As a side note, the social barriers to entrepreneurship (*e.g.* shame of failure) are well-recognised, but policy instruments are less clear in this domain. More likely, reducing barriers will entail a slow cultural process of dispelling myths and taboos around business failure.

Regulation and Governance in the Commercial Scale-up and Technology Venturing Modes: *Protecting Intellectual Property*

A key policy consideration at the "frontier" of technology is ensuring the appropriateness innovation through effective intellectual property (IP) law (Teece, 1998). Technical innovations in RET have become increasingly valuable and global patent growth in this area has been rapid. The legal and institutional frameworks for protecting intellectual property are central to ensuring continuing investment in Technology Venturing R&D.

Developing Infrastructure

Energy technology requires significant infrastructure. Public policy can support investment in infrastructure that might not otherwise be developed if left completely to private investment. Some mode-specific infrastructure policy approaches are presented below.

Infrastructure for Commercial Scale-up and Adaptation Modes: Grid Extension

Open, reliable, timely and affordable grid interconnection constitutes one of the most important success factors for large-scale renewable energy capacity growth. In many cases, the costs associated with extending grids to the location of high-quality renewable energy resources is relatively high, often beyond the means of a single project developer. In such cases, new renewable energy deployment—and by extension, innovation—suffers from such a bottleneck, but public policy can help to facilitate a solution. In some cases, this requires regulatory approval of full- or majority-cost recovery of transmission projects by incumbent utilities, raising important questions of regulatory purview and posture.

Infrastructure for the Technology Venturing and Commercial Scale-up Modes: *Regional Energy Development Parks*

The cost of site selection and, in many cases, transmission interconnection can be a barrier to new or emerging RETs. Governments could help to resolve permit and regulatory issues by creating pre-approved geographic zones in which to locate and/or construct cutting-edge projects. In some cases, transmission extension expenses may be "socialised" rather than levied directly to project developers. This means that expenses are undertaken by government agencies, since these agencies are often charged with furthering the public interest. Designating such locations for innovative projects preserves capital that developers might have otherwise spent on siting, bureaucracy and transmission inter-connection (BNEF, 2010). China has cleared the way for siting multiple GW of wind farms (BNEF, 2010). While not aimed, *per se,* at bridging the "Valley of Death", ***"the stage at which technology systems have proven themselves in demonstration projects but cannot yet generate enough revenue in conventional energy markets to sustain themselves",*** it does support the aim of commercial scale-up.

Providing Finance

Debt and equity capital promotes the diffusion of innovations, whether in the form of new products, processes or business models. Public sources of finance can complement private finance in supporting RET innovation. Some mode-specific approaches to finance are presented below.

Finance in the Adaptive Innovation Mode

Customised access to finance is crucial for the Adaptation Mode, both for customers of off-grid or mini-grid RET systems and for entrepreneurs breaking new ground on new, distributed or utility-scale business models. Some emerging strategies and approaches are presented below.

Mixed finance model

In the mixed finance model, the government provides a fixed subsidy and the user bears the remaining costs. Interestingly, this model is perhaps best established in the form of fossil fuel subsidies. When deployed in RET settings, mixed finance may include elements of cross-subsidisation from other consumer groups that are better equipped to pay. Additionally, this strategy can leverage aid support, for example when a non-governmental organisation donates all or part of the equipment or covers the costs. However, this latter strategy should be designed with caution in order to ensure eventual economic self-sufficiency.

Cooperative model

In the cooperative model, the community pools resources and jointly owns the energy system (*e.g.* mini-grid or collection of solar home systems). Such models have shown generally positive but often mixed results. A World Bank study (Kariuki & Schwartz, 2005) suggests that private, profit-based modes of small-scale electricity provision may be more sustainable. There are notable exceptions, however, such as Creluz in Brazil, which successfully supplies energy to over 80,000 customers, and IBEKA (the People Centered Economic and Business Institute) in Indonesia, which deploys a cooperative model to bring electricity to more than 40 communities (Bardouille, 2012).

Donor finance within a "wrap-around" strategy

Various international finance institutions have integrated end-user finance schemes within broader strategies to accelerate industry growth. For example, the United Nations Environmental Programme (UNEP) supported the Tunisian solar water heating market by 800% over three years (UNEP, 2008) through a coordinated finance strategy. In this approach, households were paired with local solar water heating firms; commercial banks provided the financing; the electric utility took out loans which were repaid through utility bills; the Energy Ministry corrected a fuel subsidy distortion; and UNEP and the national energy management agency managed the overall mechanism. Similar approaches are now being introduced in 11 other countries (UNEP, 2008).

Financing the Commercial Scale-up Mode

Finance in the Commercial Scale-up Mode can either provide growth capital to firms seeking to scale up production, or late-stage risk capital to help cross the so-called "Valley of Death". A range of mechanisms have been proposed (and some have been tested) to address these challenges:

Public Credit Lines

Debt financing provided by government authorities can help to provide growth capital for proven technologies or risk capital for emerging technologies. For example, the National Development Bank of Brazil (BNDES) maintains more than a dozen individual financing lines to promote international participation in ethanol projects (IADB, 2007). These funding lines cover various activities, such as equipment leasing and purchase, technology development, bond financing, agricultural systems and export lines of credit.

Public credit lines have also been deployed in the form of export credit assistance; in other words providing low-cost debt capital to domestic firms as they seek to build market share abroad (Lewis & Wiser, 2007). Export credit strategies were deployed by Denmark and Germany in support of wind technology growth in developing countries (ibid). However, such strategies may increasingly conflict with supra-national trading agreements (European Commission, World Trade Organization, etc.).

It may also be the case that public funds are specifically targeted to encourage greater private lender participation. For example, public credit lines paired with private "mezzanine" loans would support clean energy projects as a hybrid form of capital between debt and equity. In this strategy, a (minority) government funder would accept more risk without full financial compensation. Private investors, in exchange for investing the majority of capital in the fund, would be secured by the junior position of the public investor. In other words, private investors would be paid back before the public investor, but additional gains would be shared equitably. One such model is the "Fund for Investment in Environment and Rational Use of Energy" (FIDEME) in France (Jamison, 2010).

Government-Backed Commercialisation Finance Investment Entity

This mechanism entails an entity that would provide government support — likely in the form of loans or loan guarantees – to private investment funds that would be formed to address the project financing gap. Seeded with public funding, such an entity would operate in a relatively autonomous manner, perhaps leveraged via a "delegated investment authority" partnership with already engaged private sector institutions. One model is the United States Overseas Private Investment Corporation (OPIC), which supports private equity funds investing in major projects in developing countries. Another model is the California Alternative Energy and Advanced Transportation Financing Authority (Jamison, 2010).

Delegated Investor Programme

A separate but related idea involves an entity delegated with commercialisation finance authority and charged with responsibility for assessing and assuming technology risks by governments. Such an entity could distribute some decision-making responsibility by delegating public capital to existing, qualified private sector institutions empowered to make decisions (also involving substantial private capital) on an *ad hoc* deal-by-deal basis. Such a programme would likely establish regional investment "banks" close to their respective energy markets to make investment decisions (BNEF, 2010).

RET Efficacy Insurance (and Re-Insurance)

"Project finance," a form of structured finance, allows infrastructure and power plant developers to access sources of debt finance, which can significantly lower total capital costs. In the conventional energy sector, a complex process of contractual risk mitigation has evolved to manage utility-scale energy infrastructure project finance (See Appendix B). Insofar as technology risk is a factor for emerging RETs, some form of strategic support may be required.

One bottleneck for emerging RETs is the cost of insurance, compounded by insurer hesitancy to backstop product performance. Commercial insurers with appropriate levels of technical expertise (potentially supported by independent experts, national laboratories, etc.) could assess and support such selected technologies with "efficacy insurance" and receive support in turn for a portion of their risk in the form of publicly guaranteed "clean energy reinsurance pools." One model is the Terrorism Reinsurance Act in the USA, which backstops commercial insurers against losses incurred by major terrorism attacks (BNEF, 2010).

Finance in the Technology Venturing Mode: *Access to Risk Capital*

Risk—or "venture"—capital is a class of private equity funding that is thought to be essential for investing in emerging technologies. While private sources of risk capital are typically organised in independent venture funds, other sources are also important to note. For example, many major multinational corporations manage strategic investment funds with which they acquire start-up firms. Cultivating an active risk capital ecosystem is crucial for Technology Venturing.

Internationally, experiences are mixed. Lerner (2009) reports on the many failed attempts to cultivate a risk capital sector. One of the few successful examples is Israel, where not only a venture capital industry but also an active RET risk capital sector, has emerged over the past 20 years. The Israeli Government's actions in supporting innovation generally, and in particular its focus on RET, owe much to the Yozma Programme, a domestic venture capital sector initiative launched by the government in 1993 (Lerner, 2009).

Creating Markets

Supporting the creation of markets is a unique role for policymakers and is often crucial for providing stable conditions for the development of innovation ecosystems. Some general and mode-specific policy approaches are presented in this section.

General policy approaches: *Demand Support*

Beyond increasing deployment of RETs, demand-side measures can provide critical support to cultivate and stabilise innovative ecosystems around new (or commercially mature) technologies. Demand support is important across all modes, but, depending on context and RET, this support may take quite different forms. For example, in the Adaptation and some Commercial Scale-up contexts, demand support may be designed to create protected market niches for "off-the-shelf" technologies to expand rapidly in the electricity generation portfolio. In Commercial Scale-up contexts in which "pre-commercial" technologies are being moved to market, demand support will be directed at providing guaranteed markets in which to begin to realise economies of scale and learning-by-doing effects. Some policies that support these objectives include:

Public procurement

For example, in the early Commercial Scale-up phase of solar PV (1990s), German state-level policies supported solar installations in schools (Jacobsson & Lauber, 2006), creating a large and publicly-guaranteed market. Similarly, in the Adaptation Mode, donor funding may stand in for public procurement. For example, the Global Environment Facility (GEF) and the United Nations Development Programme (UNDP) have funded solar systems in schools and hospitals in Tanzania (Bardouille, 2012). Similarly, with the GEF in the Technology Venturing Mode, public procurement of advanced energy technologies for defense and space applications has provided critical early-stage support to emerging technologies (Edler & Georghiou, 2007).

Stimulating private demand

Targeted public incentives to support private investment are well-researched in their ability to nourish critical mass in RET ecosystems. Especially at the Commercial Scale-up and Adaptation stage, such policies (*e.g.* Feed-in Tariffs, renewable energy obligations) have played a central role in inducing new entry, R&D expenditure, value chain creation and political credibility (Jacobsson & Lauber, 2006).

Hybrid public-private finance

Demand support is also important in the Adaptation and Commercial Scale-up Modes. In the Adaptation Mode, examples include the India PV Market Transformation Initiative, supported by funds from the GEF, which was designed to spur retail market demand for solar home systems. While this programme was designed secondarily to induce advanced PV manufacturing capacity growth (*i.e.* as a Commercial Scale-up strategy), ex-post analysis suggests that its main impacts were in stabilising the retail end of the innovation ecosystem (Haum, 2012).[34]

34 In terms of driving market demand, PVMTI achieved notable results: the financing provided to PV retailers was estimated to have increased sales of solar home systems by approximately 30% in India (Haum, 2012).

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