Framework for Modeling Technology Policy: Renewable Energy in Abu Dhabi

Nazli Choucri, MIT (nchoucri@mit.edu)
Daniel Goldsmith, MIT (dgoldsmi@mit.edi)
Toufic Mezher, MIST (tmezher@mit.edu)

Abstract. This paper presents a framework for modeling technology policy for Abu Dhabi, an entity of the United Arab Emirates (UAE). Abu Dhabi's general objectives are to maintain a level of economic and sustainable development and to increase skill formation and capacity building. The immediate dilemma is to meet future energy demand for electricity and water desalination but at the same time reduce C02 emission. This paper presents a modular approach for using system dynamics to determine the best technology strategy policies to meet these objectives.

I. Introduction

Increased knowledge intensity of economic activity worldwide – in conjunction with the quest for sustainable development managing propensities for climate change – is placing a special responsibility on technology policy, broadly defined, and for technology use in individual sectors of the economy more specifically. Increasingly, technology strategy will have to bear the burden for national development and for steering the economy in a sustainable direction. Framing and modeling technology policy is becoming a critical capability in the domain of science and technology in order to better represent the connections between determinants, decisions, and consequences.

1.1 Purpose

This paper presents a framework for modeling technology policy for Abu Dhabi, an entity of the United Arab Emirates (UAE). Abu Dhabi's general objectives are to maintain a level of economic and sustainable development, to manage potentials for climate change, and to increase skill formation and capacity building. More specifically, the immediate dilemma for this Emirate is to meet future energy demand for electricity and water desalination and, at the same time, to reduce the environmental impacts of energy use. This dilemma can be resolved only by resorting to alternative energy sources other than fossil fuels.

1.2 Context

We select to focus on Abu Dhabi in light of three imperatives:

First, this case illustrates a set of countries that are energy-rich and major oil exporters, but singularly scarce in water resources and must rely on desalination.

Second, it highlights the immense challenges and complexities associated with technology policy in this critical situation, when water is available only through desalination, and desalination is predicated on energy use.

Third, this case signals how the design of technology policy (and modeling scenarios) to meet national needs must take into account new priorities and strategic commitments -- namely to reduce C02 emissions, support sustainable development, and emphasize capacity building buttressed by prospects for technology development.

Each of these imperatives is significant in its own right. Jointly, they amount to major challenges for modeling technology policy. This paper provides an introduction and overview of these complex challenges, and presents a framework for modeling and analysis.

1.3 Scope and Sequence

Against this brief background, Section 2 presents the case at hand and highlights the challenges and dilemmas. Section 3 develops a 'mapping' approach to the *policy* issues, presented as a 'story' around a set of interconnected relationships. Our purpose in this section is to provide a broad context for the domain of technology policy.

Based on this 'mapping' and 'story line,' Section 4 focuses on *methodology*, and derives a causal loop diagram which will guide the overall modeling activities of this research initiative. We proceed thus in order to elicit reactions and critique to help guide the next steps in modeling technology policy.

2. Abu Dhabi - Policy Context and Modeling Challenges

Abu Dhabi is part of the United Arab Emirates. The UAE is an oil producer that relies largely on export earning for its development. Located in the Arab Peninsula, it shares many of the features of its neighbors, the other oil rich countries of the region.

The First World Future Energy Summit was held in Abu Dhabi in January 2008. At this Summit the Crown Prince of the UAE announced a new strategic initiative to invest in sustainable development strategies in order to find and harness future sources of energy for the world, to protect the environment, and to preserve natural resources for future generations. This policy statement was buttressed by two announcements, each in the nature of a commitment.

The first announcement was the investment of 15 Billion USD in the new Masdar Initiative. The eventual building of Masdar city is seen as part of the Masdar initiative and it is expected to become the first Zero Free Carbon City in the world in the heart of Abu Dhabi (www.masdaruae.com). The second announcement was the creation of the Zayed Award for Future Energy.

This policy strategy, designed as leapfrogging stewardship, represents a commitment to support renewable and sustainable energy technologies. In this connection, the main government objective is to increase the use of renewable energy and energy efficient technologies in order to control CO2 emission in the long run.

2.1 Energy and Water

Fossil fuels have been the main drivers of UAE's economic growth for the past 30 years. This growth resulted in an increased population and overall higher living standards. Predictably these trends created greater demand for electricity and water. Figure 1 and Figure 2 show the demand for electricity and for water in Abu Dhabi – with forecasts to 2015.

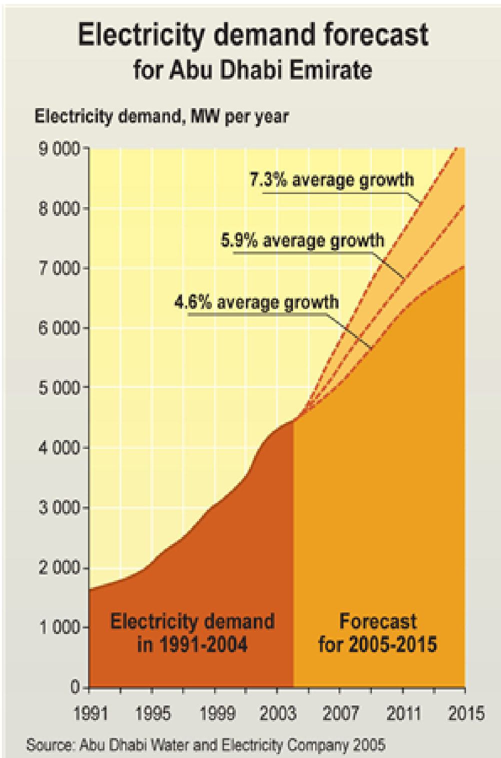


Figure 1 Electricity Demand (source: www.soe.ae)

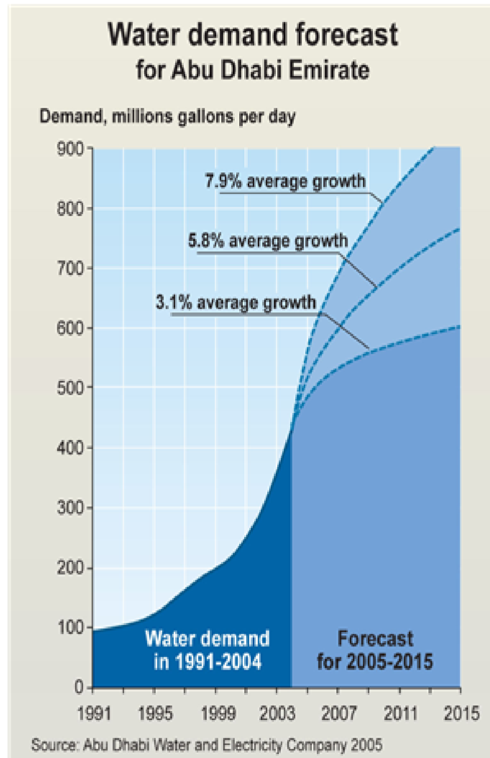


Figure 2. Water Demand in Abu Dhabi (source: www.soe.ae)

The main source of air pollution in the country is from the oil and gas industry followed by electricity generation and water desalination. Natural gas fuels over 99 percent of total electricity generation, the remainder being based on oil.

Central to this paper is the reality the UAE and other Gulf states rank high in CO2 emissions per capita and are among the highest in water consumption per capita (United Nations Statistical Division, Environment Agency - Abu Dhabi). Thus the tight coupling of energy and water is a fundamental feature of the economy. In this connection, we note that the water policy in the Abu Dhabi Emirate has been largely based on increasing supply rather than managing demand. Figure 3 shows the sources of CO2 emissions in Abu Dhabi for 2005.

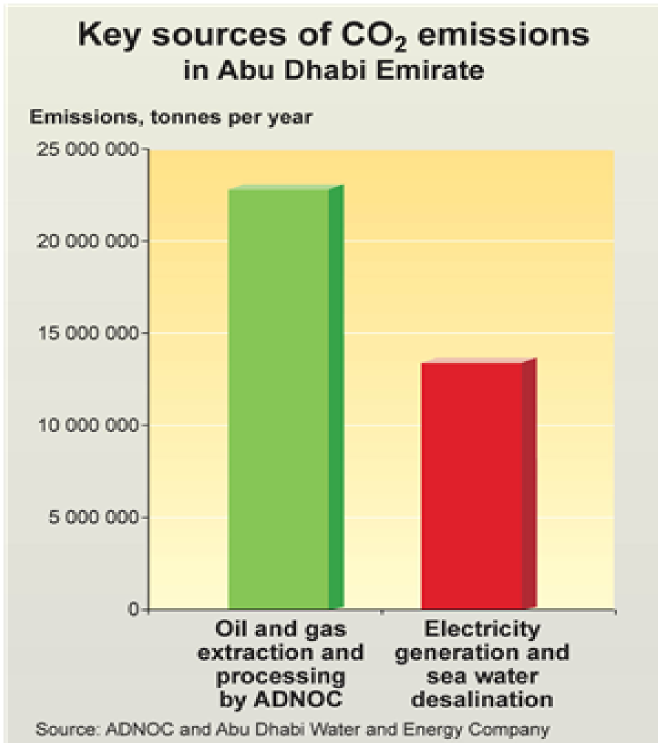


Figure 3. CO2 Emissions in Abu Dhabi
(source: www.soe.ae)

2.2 The Policy Problem

At a minimum, one of the most pressing policy problems for Abu Dhabi is to reduce the gap between (a) the expected levels of CO2 emission, under business as usual conditions and (b) the desired level under a scenario that would retain current levels unchanged well into the future. In essence, this would be a reduction in emissions while at the same time maintaining growth in the economy. In Figure 4 we present a simplified view of this dilemma.

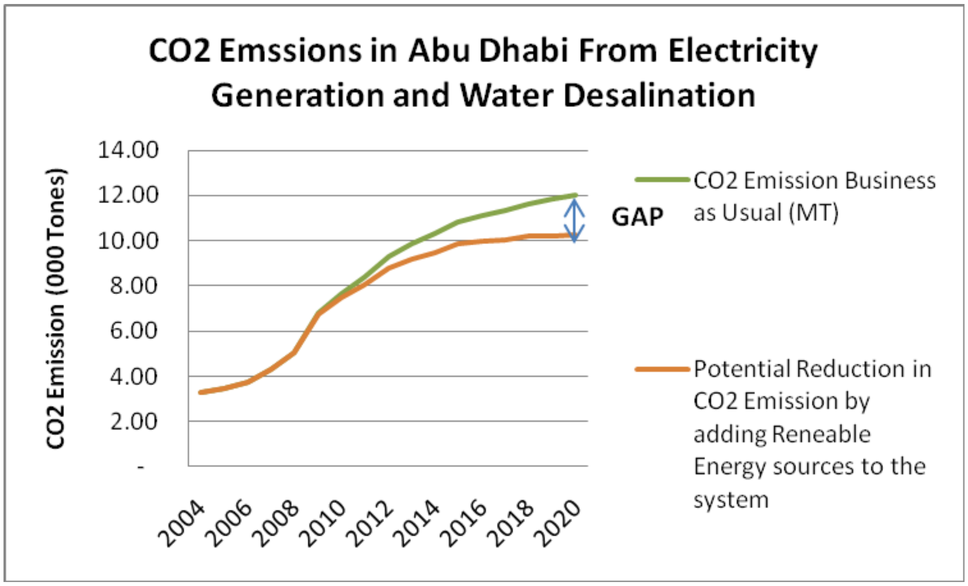


Figure 4 The Policy Problem - Simplified

2.3 Technology Frontiers

With respect to framing technology policy, we shall focus on 'frontier' issues, namely those related to (a) key elements of sustainable development, (b) the role of solar energy, and (c) the reliance on desalination as the main source of fresh water.

For *sustainable development*, we shall highlight technology features that enable, for example, greater de-massification, de-materialization, and de-spatialization in the provision of energy and of fresh water, as well as in transitions toward overall sustainability. We shall consider the energy sector as a whole, but our focus is on s*olar energy* and its sources and uses. In the water sector, we will concentrate specifically on *desalination* technology, while also taking into account contextual issues.

Solar energy is increasingly recognized as an important part of the energy mix for many economies and in many regions of the world. However, it remains in the domain of emergent rather than in traditional sources of energy. While the theoretical and conceptual foundations are relatively well understood, the commercial and operational possibilities remain disputed. Given the range of designs and technologies, choices will have to be made.

Desalination technology is well understood and operational throughout the Gulf region. Desalination is energy-intensive, thus the connections to the energy sector cannot be ignored. Given the scarcity of the region's water resources, desalination is likely to become more, rather than less, salient in the decades to come. Invariably, the region's water profile will continue to play a critical role in any strategy toward sustainable development. The energy intensity of desalination amounts to a structural condition characterized by constraints that cannot be reduced on short order.

3. "Mapping" the Research Domain

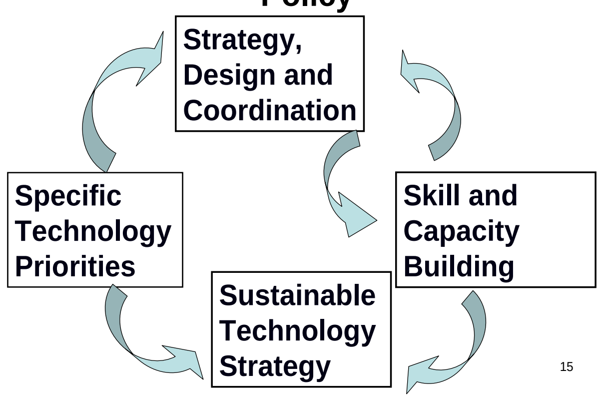
Against this background, we now turn to the framework issues. First we present a simplified high-level view of the context for the critical gap problem. Second, we shall then present a 'full-mapping' of the research and policy domains within which to focus the modeling effort more precisely. This "mapping" must best be interpreted as a "story" of the situation in Abu Dhabi, the policy context, and the ways in which the broad as well as the immediate challenges are perceived by the policy and scholarly communities in the region.

3.1 Technology Policy – High Level View

Given that technology policy is an inherently complex issue area – irrespective of the specific technology or the policy context at hand – dynamic complexity arises from interactions among system features that form the basis of technology policy planning. In general, technology policy decisions are characterized by tradeoffs.

Policies may generate transitory benefits while in the long run challenges grow more difficult; outcomes are history dependant—taking one path may preclude others, and actions may be irreversible; and decisions are tightly coupled—the important sectors in the system interact with each other as well as with the natural environment. Figure 5 shows a stylized point of departure for framing the overall research. Each of the boxed components consists of complex processes that require careful delineation.

Figure 5
Modal Elements of Technology Policy



Source: Derived from related analysis in *Mapping Sustainability* (Choucri, et. al. Eds. 2007), and earlier research focusing on mapping technology development, MIT Research Team, N Choucri, S. Madnick, M. Siegel, D. Goldsmith (internal memoranda 2007).

The *generic* elements pertain to technology policy and development that hold across any domain of activity, sector, or technology. These include (a) overarching goals and objectives, (b) essential actors and resources, (c) dynamics of transformation of intent into action, (d) the imperatives of skill and capacity-building, and (e) the actual implementation or performance factors.

The *idiosyncratic* features of technology policy are those relevant to solar energy and to desalination technologies. The modules presented in Figure 5, for example, are not likely to differ from case to case in their overall configuration, but the variables in each module will differ and represent the particular situation or domain at hand.

3.2 Mapping Technology Policy – The Logic in "Story Form"

Given the contextual and situational features of the Gulf oil producing countries in general and of Emirates more specifically, we find it useful to address the policy logic of the leadership in dynamic evolutionary terms. Accordingly, we first highlight the key variables (or clusters of variables) as seen from a policy perspective, and then we show the evolutionary logic in diagram form.

3.2.1 Critical Variables and Decision Points

The "story", which is derived from Figure 5, begins with the stated objective of Specific Technology Priorities – as a point of departure – and ends with Sustainable Technology Strategy.

1. **Specific Technology Priorities.** The government of Abu Dhabi is making a commitment to reduce this emission. Specific technology priorities must be selected in order to meet reduce CO_2 emission due to electricity and water production. Approximately, one-third of the CO_2 emission in Abu Dhabi (see Figure 3) is from energy use for electricity generation and water desalination. (CO_2 emission from oil production is not within the scope of this project).

2. **Strategy Design and Coordination.** In order to meet desired future energy renewable energy sources must be considered. Concentrated Solar Power (CSP) plants are well suited for an arid-desert like country (Tester et al., 2005; NREL, 2006). Similar plants were built using CSP technology California, Nevada, Arizona, Spain, among others. Masdar City in UAE will commission its first 100 MW CSP plant, Shams 1, in 2010. Even 'simple' decisions as building power stations and desalination plants adjacent to each other can also save energy because the desalination plant can profit from the heat exchange in the power station. In addition it is important to ensure that all resources needed to operate solar technology are readily available. (Of course, CSP technology could be undermined if new competing technologies emerge.)

3. **Skills and Capacity Building**. The development and/or use of renewable energy technologies require resources (such as people, money, infrastructure, institutional

supports, and operational processes) – all critical inputs needed to produce and operate the new plants.

All of the above means that any gap between actual and desired inputs (for any input) must be closed in order to insure continuity of production. All these inputs are tied to the skills and capacity building of Abu Dhabi. For example, human resources must be available to design, build, and operate renewable energy plants. The financial resources must be secured through the funding of various schemes between the public and the private sectors. In addition, access to the latest technologies and processes to produce solar energy is probably needed. (This can be done, for example, by building local capacity in solar RE, including local capacity for research and development, or through continuous partnerships with other countries.)

4. **Sustainable Technology Strategy.** Given physical conditions and the cluster of variables generally known as "carrying capacities", it is useful to determine what it takes to actually sustain solar energy use and economic performance. Constraints imposed by carrying capacities must take into consideration physical constraints and other possible limiting resources. For example, land can be a limitation because solar power plants require large physical space, and so forth.

The above captures most if not all of the key elements in the government's policy frames. At the same time, we must consider questions such as:

(a) Where is accountability 'located" in the technology policy process?
(b) How are resources allocated?
(d) How are priorities determined?
(c) Where are the constraints in the flow of information?

For modeling purposes, such questions are important to help represent the operational aspects of technology policy and to explore their impacts on the process as a whole.

3.2.2 Logic of Technology Policy – Visual Representation

We now turn to a visual representation of the forgoing policy narrative by working through the numerical sequences, starting with item (1) through to item (4).

In Figure 6 we present a mapping of the entire domain of relevance. It is strictly a contextual rendering of critical relationships. *We use the causal idiom for representation purposes only.*

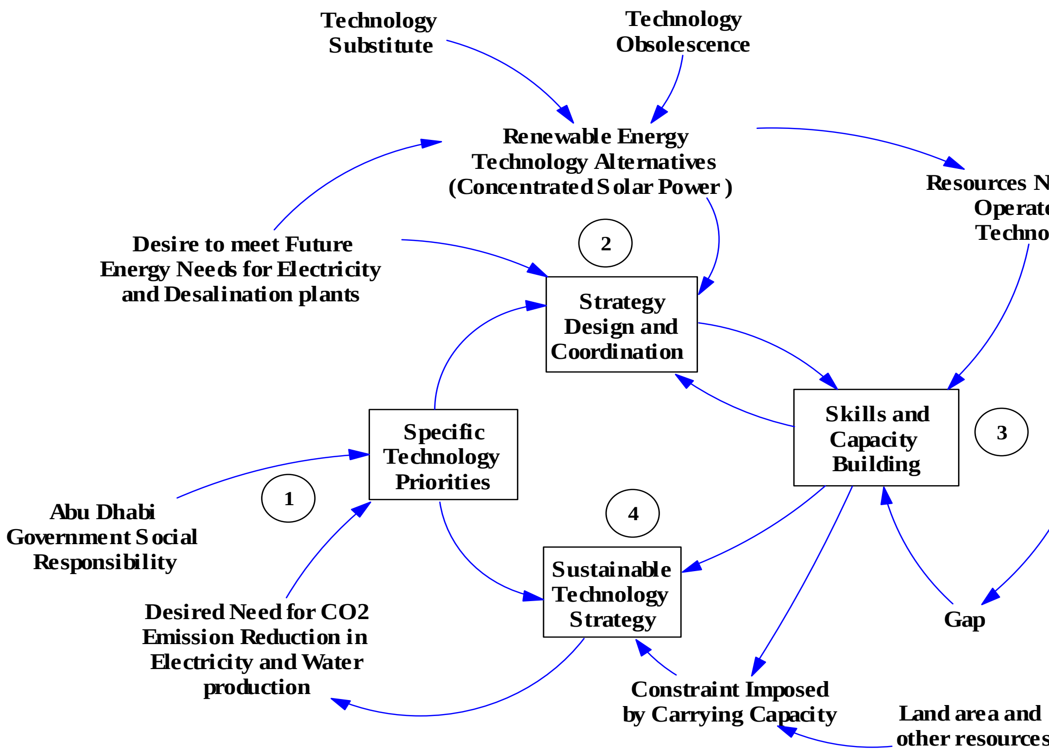


Figure 6 Mapping the Logic of Technology Policy

4. The Modular Approach - A Causal Loop Diagram

4.1 Situating the Framing Approach

Relatively few studies address the issue of climate change, and alternatives energy and their resources using a modular approach and system dynamics tool. Fiddaman (2007) uses system dynamics to develop practical policies and promote a shift in the regulatory paradigm of policymakers and the mental models of the public in the context of climate change. Ford (1997) documents the body of work that system dynamics practitioners have accumulated over the past several decades that contributed to useful change in the electric power industry.

Dyner et al (2005) apply system dynamics to evaluate and measure the factors that contribute or hinder the development of efficient, viable, and appropriate access to energy provision in remote rural areas by using a multidisciplinary and participative perspective. Serdar (2003) constructs a system dynamics model for policy analysis in Turkey with respect to technology improvement and compares various technology improvement policies. Finally, Grobbelaar and Buys (2005) assess the ability of the National System of Innovation to adjust to change and the impact of new decisions that have to be made to improve the system. The modeling includes R&D activities and human resources capacity.

4.2 Modular Approach and Causal Logic

These challenging substantive, policy, and strategic issues reinforce our decision to model and analyze technology policy process in *modular terms*. Given the complex nature of policy formation in general and in the technology domains more particularly, the modeling imitative must address generic, idiosyncratic, as well as situational features.

Cutting across all relevant elements of policy are two significant goals, namely, to (a) position Abu Dhabi for long-term sustainable development, and (b) increase knowledge intensity of economic activity. Recall that these two objectives were signaled earlier, in Figure 5 in relation to (i) sustainable technology development strategy, and (ii) skill formation and capacity building. Figure 7 below presents the causal loop diagram of goal-seeking dynamics.

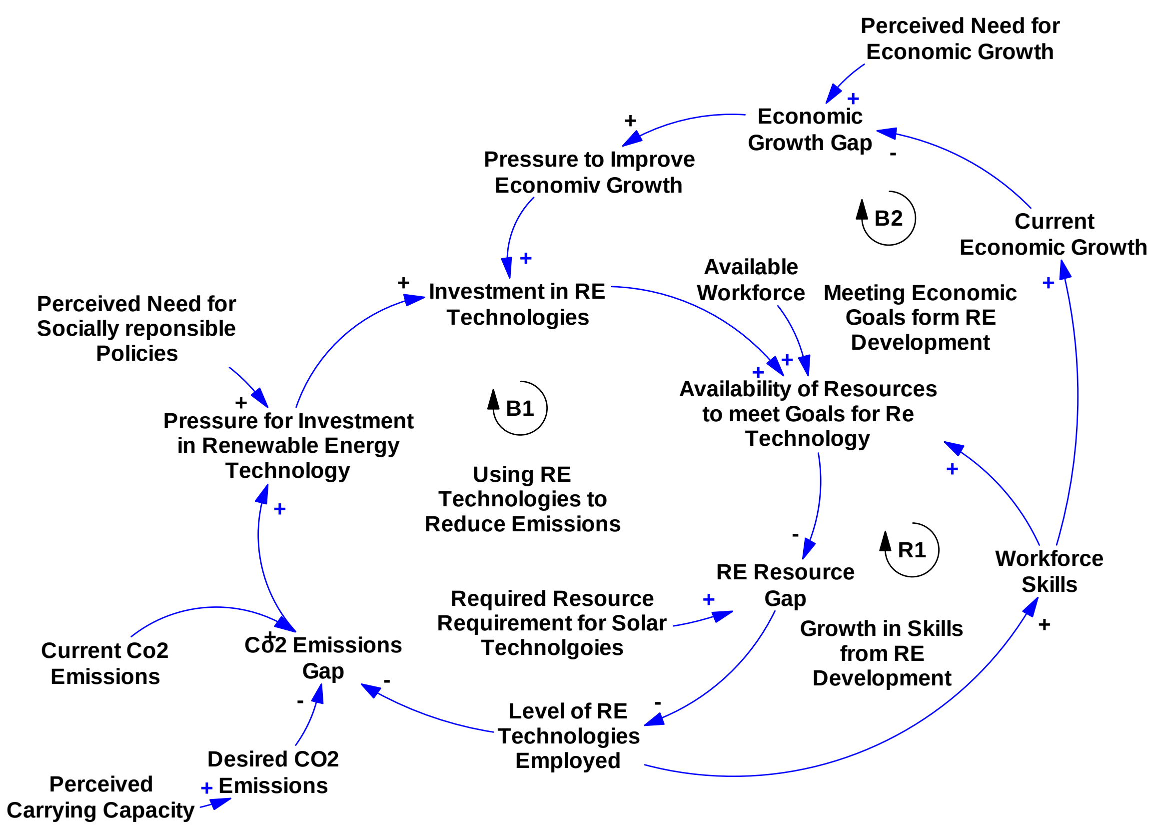


Figure 7 Causal Loop Diagram – Skill Formation and Sustainable Technology

4.3 Feedback Dynamics

We now highlight three key feedback loops that can be used to explain variation in success regarding substantive, policy, and strategic challenges.

First, loop B1 shows the intended policy of using renewable energy (RE) technologies to reduce CO2 emissions. That is, strategic investments are made to increase the resources available for RE. Over time, this investment increases the technologies in use, and thus closes the gap created by policy goals aimed at aggressively reducing emissions.

Similarly, loop B2 presents the economic rationale for investment in renewable energy technology, namely that of: increasing knowledge intensity and economic activity.

Finally, loop R1 presents an endogenous driver of the pace in the gap closing behavior of loops B1 and B2. In other words, renewable energy technology investment has a second-order effect—continuously increasing the skill level of the workforce and allowing for further RE technologies—thus meeting the governance demands of both CO2 reduction and economic growth.

An important issue, however, is this: are the delays between the loops significant enough to subvert change? For example, will RE investment lead to CO2 reductions in the short term, but not economic benefits (because B2 is delayed, and thus lead to abandonment of this strategy? Or, will the delay for R1 be significant enough that only minor progress is made on RE technologies before shifting course (leading to an overshoot and collapse behavior)?

In sum, understanding the key time delays in the system and aligning policy to accommodate delays is a necessary governance function, as highlighted in Figure 7.

5. Conclusion and Next Steps

This paper presented an overview of the challenges related to energy and water in Abu Dhabi. We developed a mapping of the overall research domain surrounding renewable energy technology policy in its strategic context, and proposed a modular approach to deal with the complexity of the problem and the challenges to the modeling effort.

The overall goal of the modeling effort is to represent goals, functional features, physical and functional capabilities and expected user-end deliverables – all of which are essential for articulating an internally consistent technology policy in this general domain.

In the next phase of this research we shall examine the technology policy process with a particular emphasis on enhancing Abu Dhabi's overall technology *capacity*.

Specific next steps are to (1) identify the initial structural features of technology policy (2) focus on critical inputs for generating solar energy for electricity generation and water desalination (3) develop the empirical data for anchoring the parameters of the model, and (4) proceed with a full specification of a system dynamics model.

Acknowledgement

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