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DESIGN FOR COMMERCIALIZATION (DFC): A MULTI DOMAIN FEASIBILITY APPROACH FOR THE DIFFUSION OF RENEWABLE ENERGY TECHNOLOGY

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Abstract

Natural resources (coal, oil, and so forth) are used globally on such modern conveniences as transportation, industrial and energy production. Higher standards of living, rapid population growth, and technology, all contribute to an increased demand for energy. However, extracting, processing, and using these resources to generate it can cause environmental problems such as climate change, the disruption or destruction of ecosystems, a decrease in biodiversity and land, water, and air pollution.

The question is not whether natural resources will be depleted, the question is when. Therefore, society needs to do a better job of preventing the depletion of natural resources, conserving energy, preventing pollution, and developing a more sustainable way of life.

One path to achieve this goal is to increase the amount of renewable energy production and to expedite the development and commercialization of renewable energy technologies (RETs) which allow us to reduce the demand for natural resources drastically. However, RETs face several barriers to commercialization which have to be addressed for them to be commercially feasible.

Design for Commercialization (DFC), is a proposed systems approach focused at the project level which could have a significant impact in facilitating the commercialization challenges of RETs. Moreover, the actual pace of RET deployment shows the need for this approach and its importance to the education community as part of any formal engineering program or engineering education in general.

Introduction

Natural resources such as trees, oil, natural gas, and coal are being used at an increasing rate. The rate these resources are used globally on such modern conveniences as transportation, industrial production and, most importantly, energy, is a major concern. Higher standards of living, rapid population growth, and technology all contribute to an increased demand for energy and therefore, an increased use of natural resources. However, extracting, processing, and using natural resources can cause environmental problems such as the disruption or destruction of ecosystems a decrease in biodiversity; and land, water and air pollution.

Moreover, many of the same natural resources used by people are important to plants and wildlife for their survival as well. There is only a finite amount of these resources and once they have been used completely, they are gone forever for all practical purposes because it will take millions of years to regenerate them. This is not a question of whether natural resources will be completely depleted or not, this is a question of when. And therefore, society as whole needs to do a better job of preventing the depletion of natural resources, conserving energy, preventing pollution, and developing a more sustainable way of living.

A path to achieve this goal is to increase the amount of renewable energy production and to expedite the development and commercialization of renewable energy technologies which will allow us to reduce the use of natural resources drastically. However, given the constantly increasing energy demand and an economic system that heavily subsidizes and relies on fossil fuels, how can renewable energy technologies be developed and commercialized at a speed which could have a significant impact in preventing the depletion of natural resources?

Renewable energy technologies face several barriers to commercialization that need to be addressed in order to explode their full potential. Such barriers have been classified in four domains: technical, economic, operational and regulatory. Moreover, research has identified the economic domain as the dominant factor in renewable energy commercialization; specifically, the economic performance feasibility and risk of renewable energy projects.

RET development requires engineering analysis and design that exist in curriculums today. However, the engineering tools and techniques are generally taught with an individual focus and not on a holistic basis. This paper provides a system approach which integrates the various tools and techniques and could serve as a practical example in Engineering Design or Capstone courses.

The first section of this paper is an extensive review of relevant literature. This literature surveys key factors for success or failure in technology commercialization that spans the last two decades. These factors have been classified in four domains (Technical, Economic, Operational, and Regulatory) according to their impact. The next section presents the DFC model and explains how each of its main components directly addresses the key factors for commercialization identified per domain.

Finally, there is a discussion on the importance of including the DFC model as part of an engineering program as well as the importance of improving this model.

Key factors for success or failure in technology commercialization

Technology commercialization is inherently an innovation-based discipline (Balachandra, 2010)[1]. By understanding the factors that influence the success or failure in commercializing new technology, a holistic model for the commercialization of renewable energy technologies (RETs) can be developed. Such model may provide a framework for educators, RET developers, and investors, to address and overcome the commercialization barriers and to allow the successful diffusion of RETs. This is the premise behind the Design for Commercialization (DFC) model.

Commercial development of renewable energy technology began since the early 1990s, but yet the amount of modern renewable energy only accounts for 16.7% of the world's energy demand (Renewable energy policy network for the 21st century REN21, 2012)[25]. It is a clear indicator that commercializing new and emerging renewable energy technologies is still a problem which needs to be addressed.

A major obstacle to commercializing new technologies like renewable energy is the length of time to scale the technology from pilot plants to commercial production. There is a need to quickly commercialize beneficial technologies to abate natural resources depletion and alleviate the increasing demand for energy (Johnson, 2009)[14]. The demand for renewable energy is driving several alternative energy solutions, not all of which are carbon-free. Therefore, it is critical to be able to develop and commercialize technologies quickly. To do this, a concurrent engineering approach must be appropriately designed and implemented. There is evidence that its successful implementation reduces the technology cycle time and time-to-market (Sharma, 2004)[27].

One of the most dominant factors for technology commercialization failure is the unfavorable economic performance of technology (Pinkse & van den Buuse, 2012)[23], (Kimura, 2010)[16], (Patterson, 1992)[22], (Nogee, et al., 1999)[19]. Moreover, according to the study developed by Osamu Kimura[16], the factors resulting in the failure of commercialization and diffusion are classified into five patterns:

1. Unfavorable performance of the technology, such as low efficiency and lack of reliability.
2. Unfavorable economic performance, i.e., high cost and long payback period.
3. Organizational changes, such as restructuring and shifts of business strategy.
4. Market changes, which refer to unexpected changes in market demand.
5. Regulatory changes, such as the tightening of environmental regulations.

In a different study developed by (Nogee, et al., 1999)[19], the main barriers to commercialize renewable energy technologies were classified in the following categories:

1. *Commercialization barriers faced by new technologies competing with mature technologies*. To compete against mature fossil fuel and nuclear technologies, renewables must overcome two major barriers to commercialization: undeveloped infrastructure and lack of economies of scale. Developing new renewable resources will require large initial investments to build infrastructure. These investments increase the cost of providing renewable electricity, especially during the early years.

2. *Price distortions from existing subsidies and unequal tax burdens between renewables and other energy sources*. Nuclear and fossil fuel technologies enjoy a considerable advantage in government subsidies and tax benefits.

3. *Failure of the market to value the public benefits of renewables*. Technology that produces societal benefits but has little effect on a company's bottom line, will be especially undervalued in restructured markets. Moreover, research indicates that people are willing to pay more for public benefits than economic theory would suggest. However, investment in technologies where much of the payback does not accrue to the individual making the investment will always be less than the optimal investment for society.

4. *Market barriers*. Inadequate information, lack of access to capital, "split incentives" between building owners and tenants, and high transaction costs for making small purchases.

Major impediments to achieve commercial viability of new technology were found in the mid '80s during the adoption of compressed natural gas as an alternate transportation fuel in Canada (Flynn, 2002)[5]. The lack of supporting infrastructure and poor design of promotional programs known as the marketing strategy, limited the acceptability and adaptability of the emerging technology in the market. (O'Brien, et al., 2004)[20], identified barriers to commercialization and deployment of integrated gasification combined cycle (IGCC) technology and categorized these into legal/regulatory, environmental, financial, economic, cultural, and technological factors.

Commercialization and diffusion in the market can be expedited and be successful if all of the key factors are considered and dealt with in a concurrent rather than a sequential manner. Examining successful cases published in the literature, reveals that most of the key factors can be identified, as well as those driving the technology to fail in the market. Table 1 summarizes the key factors for success/failure in the commercialization/diffusion of new and emerging technologies for relevant studies published over the last two decades. Such factors as public R&D, long-term R&D support by the government, are marketing and diffusion strategies to respond to and influence market demand, investment subsidy and combination of R&D and deployment policy were the key factors to accelerate the commercialization of energy-efficient technologies in Japan during the '80s and '90s (Kimura, 2010)[16].

Energy efficiency policy is a fundamental factor for successful commercialization of new technologies in the energy area and must be considered. Developers and government have to work together to allow technologies to be diffused and to allow markets to accept them. Government plays a crucial role in renewable energy commercialization. While it is essential for government to promote deployment of technologies that are already on the market through regulations and financial incentives such as subsidies, it is also important to stimulate research and development (R&D) to supply new, innovative energy efficient technologies by publicly funded R&D (Nogee, et al., 1999)[19], (Geller, et al., 2006)[7]. Subsidies not only reduce the relative cost disadvantage of new technology against conventional technology, but also increase market volumes and thus stimulate technology learning (Kimura, 2010)[16], (Nogee, et al., 1999)[19].

Another key factor for successful commercialization of new technology that has been broadly discussed in the literature is market segmentation and strategy (Balachandra, 2010)[1].

Commercialization is the process whereby the technology comes to play a useful role in society 'Commercialization' is thus a quintessential 'market' concept, if the price is too high, people will not buy the technology; if the price is too low, the manufacturers will gain no benefit from selling it, and will stop (Patterson, 1992)[22].

Therefore, knowing the market and defining a niche is a fundamental factor to address. In new technology commercialization there are a few users who put high value on innovation or environmental friendliness of the technologies which at first are much more expensive than conventional technologies. These are innovators or early adopters in the diffusion process of the technology (Rogers, 2003)[26] who form the initial market on which the developers can expand their marketing activities. Market development based on the feedback from market experience proved to be indispensable (Pinkse & van den Buuse, 2012)[23].

It is possible to identify success/failure factors for some of the renewable energy technologies that have made their way through commercialization such as solar, both thermal and photovoltaic (PV), and wind. The Luz International Limited (LUZ) is one of the world's most successful companies in commercializing solar power plants for the utility sector with 95% of the world's solar generated electricity (Lotker, 1991)[17]. In a study conducted on solar energy, the analysis suggests that it is uncertain whether all oil and gas firms will abandon the commercialization of solar PV technology completely, as this depends to what extent they are able to generate profits (Pinkse & van den Buuse, 2012)[23].

This study highlights the importance of economic feasibility in the process of commercializing an emerging technology. Investments in solar PV increased extensively after 2000 due to increased cell efficiency (technology improvement), reduced capital costs (economic feasibility), and favorable policy, leading to an annual growth in grid-connected solar capacity of 60% from 2002 onwards (REN21, 2008)[25] whereas wind had an average annual growth rate of only 25% from 2002 to 2006 (REN21, 2008)[25].

(Foxon, et al., 2005)[6] argued that sustained investment will be needed for RETs to achieve their potential. Furthermore, they argued that a stable and consistent policy framework is required to help create the conditions for this. In particular, such a framework should be aimed at improving risk/reward ratios for demonstration and pre-commercial stage technologies. This would enhance positive expectations, stimulate learning effects leading to cost reductions and increase the likelihood of successful commercialization.

Understanding the success factors is an opportunity for technologies such as wave energy which indirectly depend on wind currents to generate energy. Even though, solar technology has proven to be efficient there is still a lot of uncertainty regarding its economic benefits. There are many solar plants but only few are making money. It is a major threat for the environment because the oil industry is leaving solar and positions itself towards a "re-carbonization" of business activities.

Hydrogen or fuel cells (FC) technology, on the other hand, has proved to be economically feasible on certain applications such as bus public transportation (Bonilla & Merino, 2010)[2]. Although it is currently in a pre-commercial phase of development with a lack of cost and performance competitiveness, current high costs and the predicted gradual cost reduction are likely to imply slow market acceptance (Hellman and van den Hoed, 2007)[9].

Table 1. Key factors for success/failure in commercialization/diffusion of new and emerging technologies

Author	Year	Key Factors for success/failure in Commercialization/Diffusion	Domain	Reference
Lotker	1991	Government tax policy, avoided cost energy pricing, lack of incentives to utility owners, lack of recognition to environmental benefits	Economic, regulatory	(Lotker, 1991)[17]
Patterson	1992	Timing, cost	Technical, economic	(Patterson, 1992)[22]
Kemp, et al.	1998	▪ Technology and infrastructure ▪ Policy and regulatory ▪ Demand factors ▪ Production factors (lack of $ resources) ▪ Undesirable societal and environmental effects of technology	Technical, regulatory, operational, economic	(Kemp, et al., 1998)[15]
OECD	1999	Lack of information, lack of financing and lack of technical expertise	Operational, economic	(OECD, 1999)[21]
Nogee, et al.	1999	▪ Economies of scale and infrastructure ▪ Price distortions and unequal Gov. subsidies and taxes ▪ No value on public benefits ▪ Lack of information by customers, institutional barriers, high transaction costs, high financing costs, lack of access to capital, split incentives among those who make energy decisions and those who bear the costs.	Economic, operational, regulatory	(Nogee, et al., 1999)[19]
Jacobsson, et al.	2000	Lack of subsidies, lack of technical standards, inadequate attention given to design for manufacturability	Economic, Technical	(Jacobsson & Johnson, 2000)[12]
Flynn	2002	Lack of supporting infrastructure, marketing strategy, subsidies	Operational, economic, regulatory	(Flynn, 2002)[5]
Rogers	2003	Market segmentation, cost	Operational, economic	(Rogers, 2003)[26]
O'Brien, et al.	2004	Legal/regulatory, environmental, financial, economic, cultural, and technological factors.	regulatory, economic, operational, technical	(O'Brien, et al., 2004)[20]

Author	Year	Key Factors for success/failure in Commercialization/Diffusion	Domain	Reference
Sharma	2004	Concurrent engineering approach	Technical	(Sharma, 2004)[27]
Foxon, et al.	2005	Sustained investment, policy framework	Economic, regulatory	(Foxon, et al., 2005)[6]
Expert panel on Commerciali-zation	2006	Publicly funded research and education; partnerships among governments, private sector and academia; Capital investment	regulatory, operational, economic	(Expert Panel on Commercialization, 2006)[4]
Geller	2006	Energy efficiency policy	regulatory	(Geller, et al., 2006)[7]
Inganas, et al.	2006	Science-industry interaction	Operational	(Inganas, et al., 2006)[10]
Hellman and van den Hoed	2007	Lack of cost and performance competitiveness.	Economic, technical	(Hellman & van den Hoed, 2007)[9]
Sovacool	2009	Lack of accurate price signals about electricity consumption, Intentional market distortions (such as subsidies), unintentional market distortions (such as split incentives)	Socio-technical	(Sovacool, 2009)[28]
National Academy of Sciences	2009	Failure to internalize all costs of conventional energy and all benefits of renewable energy	Economic	(National Academy of Sciences, 2009)[18]
Balachandra, et al.	2010	Market strategy, market-based approaches, private sector driven business model, innovative regulatory, financing	Operational, regulatory, economic	(Balachandra, 2010)[1]
Kimura	2010	Public R&D, long-term R&D support by the government, marketing and diffusion strategies, investment subsidy , R&D and deployment policy, technology performance, economic performance, business strategy, market changes, regulatory changes/policy	Technical, economic, operational, regulatory	(Kimura, 2010)[16]
Jagoda et al.	2011	Non-availability of product/service to a particular market	Operational	(Jagoda, 2011)[13]
Wustenhagen	2012	Policy that improves risk-return for investors	regulatory, Economic	(Wustenhagen & Menichetti, 2012)[29]
Pinkze and van den Busee	2012	Profit, economic feasibility	Economic	(Pinkse & van den Buuse, 2012)[23]

In addition to the key factors summarized above, few authors have studied the importance of social and cultural factors in the commercialization of renewable energy technologies. Benjamin Sovacool[28] has argued that “some of the most surreptitious, yet powerful, impediments facing renewable energy and energy efficiency in the United States are more about culture and institutions than engineering and science” (Sovacool, 2009)[28.] Such impediments are referred to as socio-technical barriers[1].

In a study performed by the National Academy of Sciences[18], key barriers for renewables were identified. These were imperfect capital markets, which includes failure to internalize all costs of

[1] Socio-technical is a term that encompasses the technological, social, political, regulatory, and cultural aspects of electricity supply and use.

conventional energy (e.g., effects of air pollution, risk of supply disruption) and failure to internalize all benefits of renewable energy (e.g., cleaner air, energy security), also known as societal costs.

As shown in Table 1, factors that involve technical capabilities such as technology performance or technical standards are part of the technical domain. Factors that represent financial measures such as profit or economic feasibility are part of the economic domain. Factors determining the long term sustainability of the technology such as supporting infrastructure or science-industry interaction are part of the operational domain. Likewise, factors related to governance and policies such as R&D support by the government or energy efficiency policy are part of the regulatory domain. The factors identified by (Sovacool, 2009)[28], were classified in a socio-technical domain that encompasses technological, social, political, regulatory, and cultural aspects.

Moreover, the commercialization factors from Table 1 were further summarized, generalized and grouped as technical, economic, operational, and regulatory domains in Table 2. These four domains are the foundation blocks of the DFC model and each component of the model deliberately addresses the individual factors through a series of engineering, financial and operational strategies that are combined in a comprehensive systems approach.

Design for Commercialization (DFC)

Many people think of commercialization as the final stage of a neat, linear process of innovation. They think in terms of someone with an idea in a laboratory, and imagine that, step by step, the idea matures into a product, service or process that enters the marketplace (Expert Panel on Commercialization, 2006)[4].

Commercialization is a complex, integrated system anchored in the world of business. It has many components that come together in different ways. Each commercialization situation is different and based on a distinct mix of factors that include: supply-and-demand issues, business operation factors such as financial strength, marketplace framework issues such as the mix of laws, government policies, intellectual property, regulatory and tax regimes, programs, capital markets and other forms of financial support that facilitate access to funding for commercialization. In addition there are issues that affect all of the preceding, such as the quality of information and its flows for decision making and the presence of alliances, networks and other forms of connection among business, governments, educational institutions and other partners.

Commercialization is not a one-size-fits-all process. Therefore, this view of commercialization is focused on the issues and challenges of RET commercialization at the project level only.
Why is DFC important? Because new technologies must be designed and developed with the ultimate goal in mind which is “successful commercialization”. Often, technologies are developed simply because they are intended to be technically superior, easier to use or more appealing. In reality, all those features are important, but they are even more important when they all come together and are integrated since the idea’s inception. Design for

commercialization (DFC) is a proposed framework that begins with the end in mind, where the main goal is the "commercialization" of RETs.

In order to expedite the development and diffusion of RETs and, therefore, enjoy the benefits of sustainable clean energy sources, we need to do a better job of making sure that every effort and every dollar spent in the pursuit of a RET project will guarantee its commercialization.

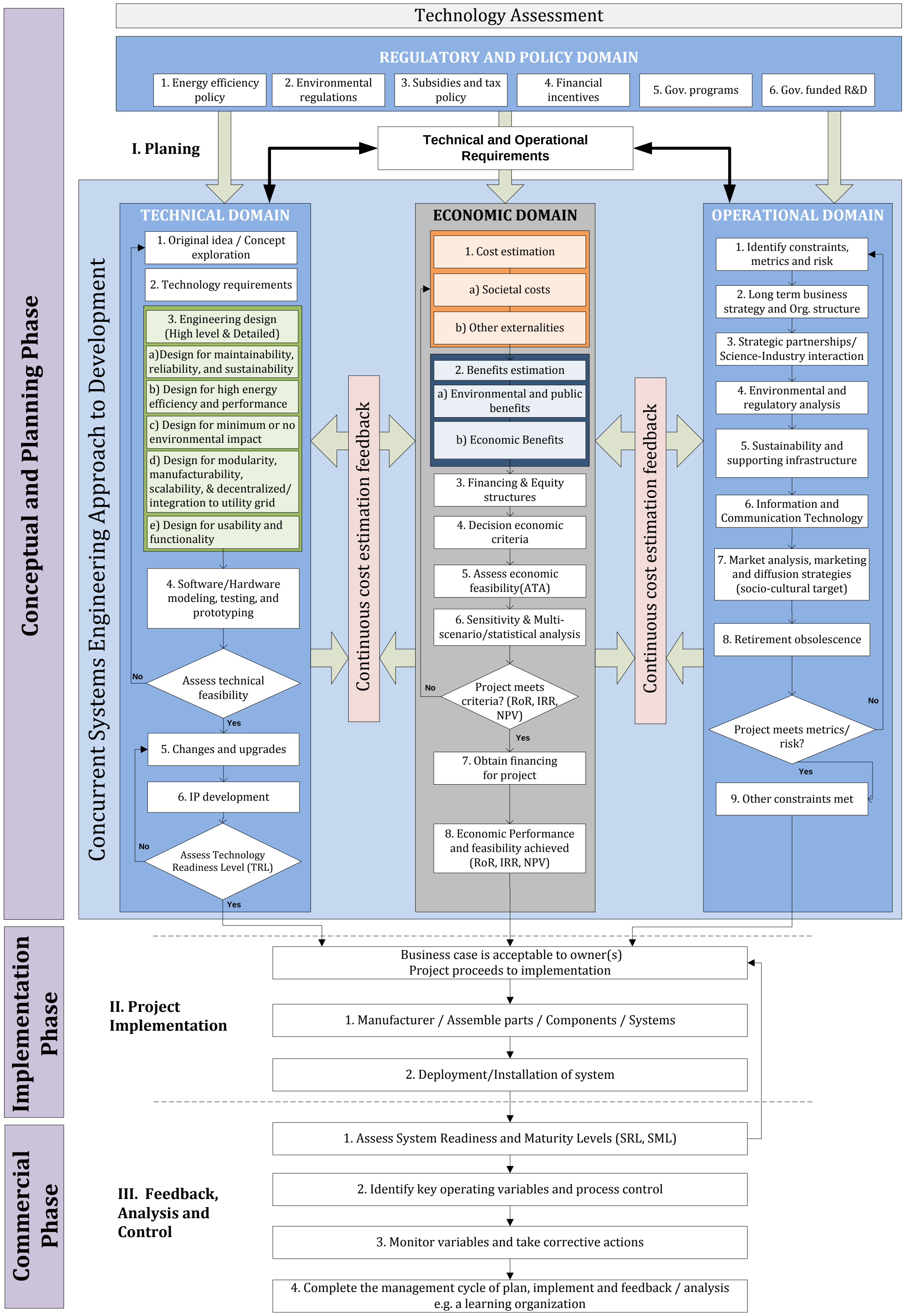
Renewable energy technologies face several barriers to commercialization that need to be addressed in order to explode their full potential. Such barriers have been classified and summarized in four domains: technical, economic, operational and regulatory policy as shown in Table 2. Furthermore, the study of such barriers should lead to the development of a holistic model for commercialization of RETs which is the premise behind DFC.

Table 2. Domain and key factors for success in technology commercialization/diffusion

Domain	Key factors for success in technology commercialization/diffusion
Technical Domain	1. Concurrent/systems engineering approach to development 2. Technology performance (competitiveness) and efficiency (technology improvement) 3. Technology reliability, maintainability and sustainability 4. Technology cycle time and time-to-market (This is achieved by implementing #1)
Economic Domain	1. Economic performance (ROI, NPV) and feasibility (profits generation) 2. Competitive/reduced cost (either capital/operating or both) 3. Financing availability and risk 4. Avoided cost (e.g. societal costs) and environmental impact (e.g. GHG emissions)
Operational Domain	5. Supporting infrastructure 6. Organizational changes, such as restructuring and shifts of business strategy 7. Market changes, which refer to unexpected changes in market demand 8. Marketing and diffusion strategies targeting innovators and early adopters 9. Private sector driven business model
Regulatory and Policy Domain	1. Energy efficiency policy 2. Government tax policy (e.g. Investment tax credits) and financial incentives (e.g. subsidies) 3. Government supported and publicly funded long-term research and development 4. Environmental regulations and policy

Design for commercialization, or DFC, is a proposed approach focused at the project level that integrates the aforementioned domains into a holistic and comprehensive systems model in order to address the barriers of RETs and to expedite their development and commercialization. DFC consists of three major phases: a conceptual and planning phase, a development phase and a commercial phase. Figure 1 represents the DFC model. DFC does not necessarily require that the RE project starts from the idea. Thus, any project in the planning phase can be undertaken by this approach.

Figure 1. Design for commercialization (DFC)



DFC represents a fully integrated systems model that provides educators and technology developers with a project level framework to study and develop commercial RET projects. DFC allows small-medium enterprises (SMEs) and decision makers to improve the selection process for RE capital projects, facilitating the flow of capital investment and securing successful commercialization.

DFC is intended for use by educators, developers, investors and researchers. Early stage developers can use it to guide their understanding in the development process. DFC further helps identify capabilities that will be required to successfully design a particular technology. In addition, an investor could use DFC to evaluate the TRL level at which a company currently resides.

Moreover, DFC will help investors to generate questions that can lead to more accurate assessments of a company's progression. DFC can also be used by educators and researchers to identify areas where the industry could benefit from more research and development.

Conceptual and Planning Phase

The conceptual and planning phase is a multi-domain feasibility study which involves the exploration of new ideas, development of new technologies, business models and operational processes. Government also plays a very important role in this phase because regulations, policies and benefits directly impact the multi-domain feasibility. The successful commercialization will depend on how detailed and elaborate this phase is undertaken. The end of this phase is determined by a positive multi-domain feasibility status in which all goals and established conditions are met.

This process is based on a systems engineering approach and has technical, economic and operational domains. Therefore, each domain should be developed concurrently in order to minimize time to market. A concurrent engineering process has been shown to both reduce the manpower required as well as the elapsed time to complete the design (Balachandra, 2010)[1]. The process begins with the study of technical followed by economic and ending with operational feasibility. Each step should be viewed as a "go-no go" decision point. As the commercialization process progresses, each step will become increasingly more costly and will involve more outside resources and experts (Goldsmith, 2002)[8].

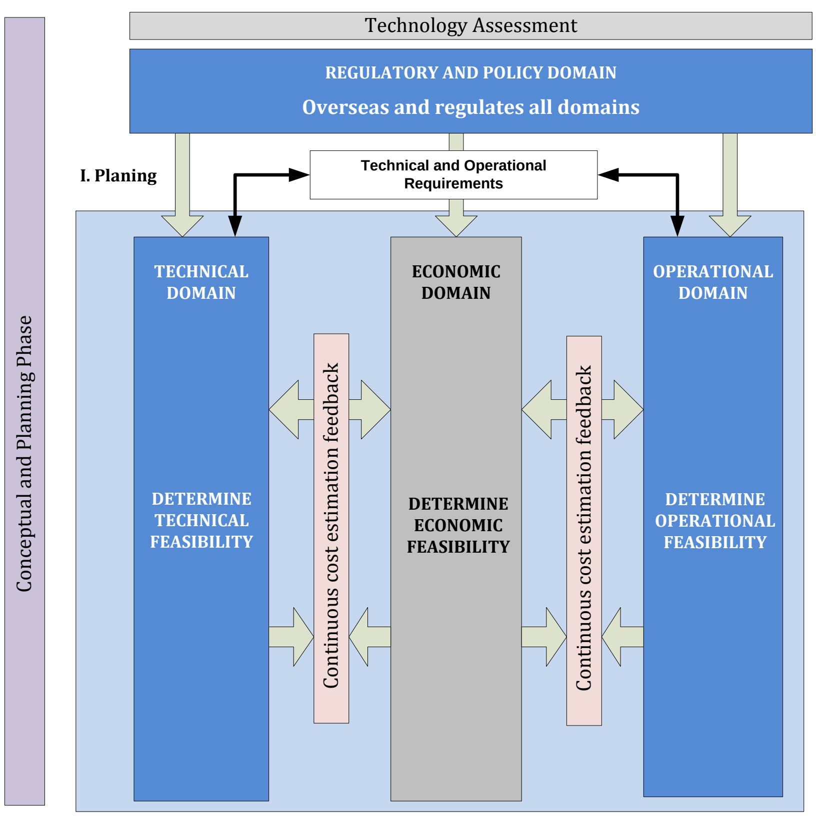
Both technical and operational domains share information that is essential for the generation of cost estimates. As the development of each domain progresses, more refined and accurate estimates are made available that feed the economic model developed in the economic domain. The goal is to minimize the variability of cost estimates. The results obtained from the economic domain, feedback from the technical and operational domains with a detail analysis of the project's economic performance. This information is used to re-evaluate technical or operational requirements and specifications that can impact the project costs (capital or operational, or both). See Figure 2.

For example, should additional hardware capital be spent to increase the equipment life from seven to ten years (Operational requirement), the economic model will produce the incremental difference in the project's economic performance. If the difference meets the economic criteria it should be pursued. This incremental analysis can also be used to provide 'targets' or 'goals' which would guide engineering design (Bonilla, et al., 2013)[3]. These approaches are examples of a Concurrent Engineering approach outlined in Figure 2 which represents the information flow in the DFC model.

In addition, the technical and operational domains share information in the form of technical and operational requirements. For instance, should the specific RET project be integrated to an existing electrical distribution system, identified as part of the sustainability and supporting infrastructure analysis performed in the operational domain. This information is translated into a technical requirement that must be incorporated during the design and engineering process performed in the technical domain. Likewise, should the technology be serviced or maintained according to a specific standard that requires 24/7 accessibility (Operational requirement). Therefore, site location, accessibility and utilities must be identified in the operational domain.

Technical, economic and operational domains generate vital information that must be shared them for the successful development of each domain. Furthermore, the flow of information throughout the development must be continuous in order to minimize risk and to secure a multi-domain feasibility outcome.

Figure 2. Information flow in the DFC model.



During this phase, the technology system, scope and key stakeholders are defined. Moreover, the decision making team should prioritize the business strategies that best fit the venture opportunity and pursue the financing mechanisms that are most appropriate.

These will vary based upon market considerations such as life cycle of the technology, speed to market, scope of launch (local, national or global), and economic attractiveness. Business strategies could include licensing, strategic alliances or partnerships, or a venture. Financing mechanisms could include debt or equity financing or a combination. Debt financing usually comes from institutional lenders while equity financing comes from other sources such as individual angel investors, venture capital, tax equity capital, private placements, mergers, acquisitions or initial public offerings. High-growth venture opportunities invariably use a variety and combination of financing mechanisms.

The conceptual and planning phase is very critical (Goldsmith, 2002)[8]. This is the time to be certain that absolutely all aspects of the project have been investigated. Failure to do a good job during this phase may well result in commercialization failure and the ultimate demise of the technology or project. Technical feasibility involves development of a working, functional and operational product that precisely addresses all technical barriers for commercialization.

Economic feasibility involves the development of a robust cost and financial model, capable of reliably assisting investors in the decision making process and to validate the benefits of financing structures that guarantee short and long term profitability. Operational feasibility involves the development of a long term business strategy as well as the necessary infrastructure to support the technology in a sustainable manner.

Technical Domain

The Technology Domain focuses on the technical development of the technology; the main purpose is to mitigate all the commercialization barriers related to technology issues, such as efficiency, maintainability, reliability, integration to the grid, etc.

Although most of the technology related barriers have been identified and incorporated in this domain during the conceptual phase, technology developers and researchers must identify and take into consideration any possible barrier as well as other risk aspects of the technology. These newly identified barriers must be incorporated in the design process as technology requirements, so that their adverse effect can be mitigated.

Throughout the technology development process the Technology Readiness Level (TRL) must be evaluated in order to determine the maturity level of the technology. Because this is a concurrent engineering process, developers and researchers must use this metric as a mean to communicate the state of development to key stakeholders.

The end of this process is reached when the technology has achieved a TRL of eight or above and has proven to be technically feasible.

Economic Domain

This domain focuses on the economic feasibility study of RET projects. The study involves the estimation of the project's costs (internal and external) and benefits throughout its entire life-cycle, as well as the analysis of financing and equity structures that can reduce the project's financial risk and improve its economic performance. As concluded by (Rana, 2010)[24], financial structures can have a major impact on renewable energy, meeting demand in an economic manner. The purpose of this study is therefore, to provide decision makers and investors with a detailed view of the project's economics that allow them to make an informed decision as to whether or not to fund it, and how to structure it financially so that the best economic results can be achieved.

The economic feasibility of RET projects is overall the most important factor in technology commercialization. Far beyond the technical capabilities or performance that any RET may have, the economic potential and, more specifically, the economic feasibility is what drives investors to deploy the financial resources needed to move technology development forward. Nonetheless, the economic feasibility by itself is no guarantee for RET commercialization success. Technical and operational feasibility are also important to achieve successful commercialization.

Furthermore, the technical and the economic domain should be executed concurrently, as the economic feasibility study heavily relies on key technical performance indicators and accurate cost estimates that can be performed during the engineering design process.

Operational Domain

The Operational Domain focuses on the long term operation and sustainability aspects of RETs. The main purpose is to mitigate all the commercialization barriers related to the technology's operational environment. RETs are designed to explode renewable resources; however, they make part of a more complex ecosystem where not only those resources are important but operational constraints such as a lack of support infrastructure are critical to their successful deployment and sustainability.

Research performed has identified multiple barriers for successful commercialization of RETs, and new technologies in general, as constraints within the operational domain. Such constraints can be directly (e.g. supporting infrastructure) or indirectly (e.g. Marketing strategy) related with the technology and play an important role in commercialization. The operational domain has been integrated into the design for commercialization model (DFC) as an important component, in order to overcome operational barriers during the conceptual and planning phase.

For a RET project to be successfully commercialized, all the operating components of the system have to be considered and analyzed. Focusing on developing the most efficient RETs at the lowest cost is not a guarantee of successful commercialization. Deploying such technologies in an area where the supporting infrastructure is inappropriate or unreliable or not easily accessible for maintenance purposes, can be detrimental for the project's commercialization and can represent a tremendous impact to the project's profitability in terms of high operating costs or revenue lost. These are just some examples of many operating conditions that need to be considered in a RET project and hence, the main purpose of this domain.

Nonetheless, a successful development of the operational domain by itself is no guarantee for RET commercialization success. Technical and economic feasibility are also important to achieve successful commercialization. Moreover, the operational domain has to be developed concurrently along with the technical and economic domains, to make sure the information is updated and shared optimally. For example, the marketing plan and execution costs have to be incorporated as part of the economic model. Likewise, the environmental and regulatory analysis is an important input for technology efficiency targets and market strategies.

Regulatory and Policy Domain

Federal, state, local government regulations, policies, and benefits are key drivers for the diffusion of RETs. They have a direct impact on all project domains (technical, economic, and operational), and therefore, the regulatory and policy domain oversees all of them.

The impact of regulations and policies on RET projects may be positive or negative depending on a variety of factors, all of which are project related. Nonetheless, renewable energy markets tend to develop as a result of supportive public policies rather than through the efforts of competitive, commercial interests (Walters and Walsh, 2011; Wiser, 2000). For that reason, it is important for the successful commercialization of RETs to leverage all existing public benefits (e.g. R&D, grants, etc.) and to consider all applicable regulations during the design and development of a RET project.

Implementation and Commercial Phase

Once the technical, economic and operational constraints are considered feasible a business plan is developed, funding is obtained and the project proceeds to the implementation and commercial phase. Traditional project management processes can be used for the implementation of RET projects. The differentiated value of DFC is obtained during the conceptual and planning phase. Implementation and deployment of the technology is the second phase in DFC (See Figure 1). It must occur gradually and interactively based on the natural cycle of supply and demand. Market dynamics will determine the pace of technology deployment.

Finally, the third phase in DFC suggests a feedback, analysis and control loop that focuses on the identification and monitoring of key aspects of the technology as well as the system as a whole. The system's readiness level (SRL) and the system's maturity level (SML) are the metrics that need to be analyzed during this phase in order to determine the overall project's performance as the system matures into the commercial phase.

This approach allows for corrective actions and future improvements so that technical, economic, operational and commercialization sustainability can be accomplished. Furthermore, key operating variables of the supporting infrastructure (e.g. Distribution systems, refueling/recharging stations, and so forth) must be closely monitored and controlled in order to guarantee sustainment over time. Monitoring and controlling such key variables would avert the collapse of the RET as a result of a lack of supporting infrastructure.

The Importance of DFC in Engineering Education

There must be a shift in the energy paradigm and the way energy is produced and used. Society must encourage the development of a sustainable energy system, a system that is technically, economically and operationally feasible and, most importantly, a system that is non-depleteable, one that does not degrade natural resources or public health.

Such systems will require the development of innovative technology and market based strategies to commercialize renewable energy technologies. Therefore, every effort must ensure these technologies have the best chance of being commercialized and that resources are not wasted. These technologies must be developed with commercialization as the ultimate goal and DFC could be the key approach on this challenging process.

Using DFC could have a positive effect on society and increase the level of awareness about the impact of energy production on public health, These impacts should be transparent to young engineers and researchers The DFC model cold be taught at the graduate or undergraduate level, as part of any sustainability engineering, engineering economics, or systems engineering course. This environmentally conscious mindset must be promoted among all engineering disciplines and should not be left to environmental engineers only. Moreover, the concept of multi-domain feasibility to evaluate projects should be a general engineering and industry practice.

This practice will promote the creation of more interesting theories and research, all geared towards the development of a more sustainable future, a future in which everybody can live healthy and productive lives without fear of running out of natural resources or destroying the environment.

DFC may serve as a framework that allows educators, researchers, technology developers and, investors to focus on key development elements of sustainable and renewable energy technologies. Elements that facilitate and enhance the multi-domain feasibility of RET projects, but also provide decision makers in the private sector, lending institutions, non-governmental organizations, and the interested public with clear criteria to substantiate their decisions.

Conclusions

Exhausting natural resources and burning fossil fuels is not a long term option for sustainable economic growth. Renewable energy technologies (RETs) are becoming the preferred alternative to the traditional sources of energy in developed and developing countries (Rana, 2010)[24]. The accelerated pace of devastation and depletion of natural resources, as well as the emission of greenhouse gases (GHG), which implies major environmental problems and poses a threat on human health, will require technological innovation and the rapid and widespread commercialization and implementation of renewable energy technologies (RETs). This paper represents taking practicable steps to promote, facilitate and finance the development of such technologies.

RETs that meet technical, economic and, operational criteria, as well as local needs and priorities, are more likely to be successfully commercialized. However, there is no pre-set answer to enhancing technology commercialization. Interactions and barriers vary according to sector, type of technology and geographic location and, most importantly, financial flows that drive technology commercialization (Intergovernmental panel on climate change IPCC, 2000)[11].

There must be a shift in the energy paradigm and the way energy is produced and used. Society must encourage the development of a sustainable energy system, a system that is technically, economically and operationally feasible, and most important, a system that is non-depletable, one that does not degrade natural resources or public health.

Such system will require the development of innovative technology and market- based strategies to commercialize renewable energy technologies. Therefore, every effort must be made to make sure these technologies have the best chance of being commercialized and resources are not wasted on the intent. These technologies must be developed with commercialization as the ultimate goal, and DFC may be a key approach on this challenging process.

Finally, the Design for Commercialization model may be used by educators, RET developers, researchers and investors to assess the multi-domain feasibility, deal with commercialization barriers and mitigate the technical, financial, and operational risk of RTE projects.

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