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Integrated Sustainability Decision-Making Framework

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INTEGRATED SUSTAINABILITY DECISION-MAKING FRAMEWORK

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Abstract

The Integrated Sustainability Decision-Making Framework (ISDMF) is an 'ideal case' framework developed at the University of Texas El Paso (UTEP) from 2012 to present to provide the most comprehensive and concise sustainability strategy and decision-making template available.

Sustainable decision-making improves community Quality of Life, but is often beyond the reach of the majority. A framework that is most approachable, actionable, and adoptable can accelerate convergence on and continued operation of a sustainable solution. Research confirms that published frameworks continuously emerge, and are infinite in number. Iterations benefit from prior work, and contribution occurs when an 'ideal case' is envisioned, best case examples are compared, logic gaps are resolved based on the incubated the 'ideal case', and improvement is proven in practice.

The ISDMF is a 'checklist', presented as a process view, to better enable effective and efficient sustainability decision-making. Prior work demonstrates that the ISDMF closely aligns with the most respected framework offerings, and expands actionability while streamlining structure to simultaneously increase approachability and adoptability. The current referenced 'best case' is the Sustainability Framework designed by the National Academies (NASF) for U.S. Environmental Protection Agency (USEPA) use. Results confirm ISDMF form and content alignment with the NASF, yet the ISDMF expands established sustainability decision-making strategy and development in two fundamental areas: (1) choreographed behavioral and economic theories, and (2) integration of Diffusion of Innovation theory.

Value of these theoretical 'integrations' is demonstrated heuristically via community case studies and comparisons for a resource and innovation. Electricity, assumed an indicator of community prosperity (Smalley 2005), is selected as the resource, and is evaluated for residential grid-tied photovoltaic technology as a community innovation decision point toward sustainability. The major U.S. cities of Portland, Phoenix, and El Paso are objectively assessed. Results confirm ISDMF additions support two electricity sustainability best practices, namely (1) cooperative action through data transparency, and (2) inclusion of adoption monitoring. These ISDMF results, if implemented in each

test case, can foster decision and action legitimacy, and thereby enable more rapid community participation to accelerate electricity sustainability where feasible.

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Introduction

Effective resource management has long determined societal prosperity by working to combat rising scarcity, risk, and cost. The Integrated Sustainability Decision-Making Framework (ISDMF) presented in this work offers a comprehensive yet concise toolset to effectively and efficiently create and evaluate strategy. Most principally, the ISDMF provides the user with proven economic, problem solving, and diffusion of innovation theories in a Framework to enable effective decision-making as a user check list for an identified resource. The Framework is designed to be approachable, meaning that most in the resource use chain can understand and apply it. Second, it helps identify specific action so that when the application is completed users should have a set of focused sustainability initiatives to pursue. Third, the range of integrated theories provides the user with recognized yet often overlooked perspectives when creating a resource sustainability strategy. The net effect of these elements is to provide all users with choreographed, developed considerations across a resource use and delivery chain. The Framework can foster sustainable resource management insight and action to guide more sustainable personal choices, policies, technology objectives, and community wide engagement.

Sustainable resource management is critical to ensure constant or improving Quality of Life. Nearly every human action has some affect on the environment, and ineffective resource management can adversely affect Quality of Life. With the recent announcement of a burgeoning world population over 7 billion (U.S. Census Bureau 2013) people, threats of resource scarcity, global warming, and pollution to Quality of Life are enormous. Effective resource decision-making is paramount for communities to confront and successfully manage these challenges.

Selection and implementation of a strategy is based on decisions taken during the development process. Many varied decision points can be applied, but for general discussion consider that three critical decision points occur when developing and implementing a sustainability strategy. Decision-makers must first decide on the assumptions that will be used; secondly, options are decided upon; and finally, a decision is made to select an option and respective actions required to implement the strategy.

Oversight or errors in any one of the decision points may result in ineffective sustainability strategy and Quality of Life erosion.

An example of faulty decision-making is reproduced in illustration 1.1. While identifying the mime's specific decision point error is impossible from the single caption, the outcome was obviously not the performer's intention. Frankly, better decisions could have been made.

Illustration 1.1: When decisions with assumptions, options, or actions goes terribly wrong (Wulff 2014)

The comic highlights, in a humorous way, that flawed decision-making can jeopardize Quality of Life or, in extreme cases, life itself. This is particularly the case when communities strive to manage resources sustainably.

A broad spectrum of decision-making approaches exists. The ISDMF developed as an integrated, comprehensive, and streamlined sustainability decision-making structure synthesized from proven economic, assessment, and adoption theories. It provides users with a novel starting point to ameliorate resource sustainability challenges across communities, independent of their size or location. The ISDMF is developed in this Introduction, and supporting theories and differentiators are presented in the Literature Review, section 2.

Once developed, the ISDMF is tested through case study analyses of three major U.S. cities to include El Paso, Phoenix and Portland regarding strategic electricity management related to residential,

grid-tied photovoltaic systems. Research observations are compared and best practices are identified to promote and opportunities for improvement in sections 3 and 4 of this work. Conclusions and Future Work opportunities are reviewed in sections 5 and 6.

The intent of this research is to develop a Framework to promote sustainable resource management through efficient, effective, and comparative decision-making. The resultant Integrated Sustainability Decision-Making Framework is expected to facilitate and distill intimidating sustainability challenges into approachable, actionable, and adoptable efforts. While elements within the Framework are not new, the fusion of contributory philosophies establishes a novel and more comprehensive platform for sustainable decision-making not available in prior work.

1.1. Rationale for the Study

"It's no longer us against 'Nature'. Instead, it's we who decide what nature is and what it will be." - Paul Crutzen, 1995 Nobel Laureate in Chemistry (Crutzen and Schwägerl 2011).

Sustainable decision-making helps ensure that communities succeed in resource preservation, demand, and economic competition. Humanity significantly invests in a wide array of analyses, innovations, and marketing plans to effectively engage the community toward sustainable action only to gain sporadic advances. In extreme historical cases and as a harbinger, errors in resource decision-making resulted in the extinction of entire cultures (Diamond, 2011). With historical examples as a backdrop, modern societies must work to assure that ideas developed and applied today provide approachable, actionable and adoptable solutions that lead an efficient migration to a continuously improving and sustainable future.

The work suggests that three options describe decision-maker behaviors that create resource outcomes of degradation, equilibrium, or renewal:

1. <u>Degradation through 'Business as Usual'</u>: This option, while the easiest to adopt since change is not required, may not insure resource sustainability. Assessments indicate that current risks of resource depletion and damage are unsustainable which may lead to

decreased Quality of Life. Several challenges are inherent to most societies: (a) population growth and increased global demand per capita for resources ensures continuously increasing competition, (b) primary resource extraction is becoming more expensive with ongoing depletion of fossil fuels, fresh water, and other resources, (c) byproducts of resource use adversely affect the physical environment, and (d) while improved technology allows for more efficient delivery of both primary and secondary resources, existing infrastructure is aging. In addition, retrofit or expansion of those conduits can be expensive. Generally, this 'laissez-faire' approach may threaten sustainability erosion through inaction, and decision-making frameworks are not applicable.

2. Equilibrium by 'Preserving the Status Quo': This approach requires minimal yet active analysis and effort to address increasing resource demands and negative byproducts of their use. With this behavior, frameworks become important for effective management of sustainability strategies, albeit community urgency is low as the intent is to only offset immediate concerns but not to enhance resource sustainability.

3. Renewal by 'Increasing Resource Sustainability': In this option, societies actively and aggressively work toward more sustainable resource solutions by applying frameworks and strategic actions. Participants innovate and implement more sustainable actions to continuously improve their Quality of Life today and for the future.

Consolidated approaches and frameworks are not widely adopted because the complexity of sustainable management is vexing and diverse in application. The expanding number of unique, localized applications combined with multiple participants can introduce subjectivity and dilute development of viable sustainability strategies and actions en mass. However, not all communities are confronted with the same challenges and sustainability approaches must then be variable. Recognition that sustainable decision-making is complex and that each participating community is subject to unique concerns requires that approaches be flexible to offer value. This inherent variation causes societies to

both benefit and suffer from resultant messaging inconsistency and diversity of existing decision-making approaches.

So, the question remains: Does a consolidated and effective approach exist that enables all participants to act on a common understanding of sustainability risk and thereby reinforce positive action? Unfortunately, the answer is a resounding “No!” As a global society, decision-makers often fall prey to circumstance and seem unable to reach outside of immediate scope. Jan Rotmans, the Scientific Director of the Dutch Research Institute For Transitions (DRIFT), summarizes the dilemma of insufficient frameworks (Rotmans 2006, p.3):

> “Scientists attempting to assess the complex phenomenon of sustainable development also failed so far to develop adequate tools to comprehensively analyze the complexity of sustainable development. Here we run into the ’sustainability paradox’: the unsustainability problems humankind is faced cannot be solved with current tools and methods that were applied – or seemed to work - in the past. Obviously, the paradox is that we cannot wait for the next generation of tools and methods (and minds). What we can do, however, is using current knowledge, tools and methods in the best possible manner, while developing a new paradigm that better reflects the complexity of sustainable development."
>
> Dr. Rotmans continued:
>
> "So we need new tools and instruments to support the sustainability decision-making process in a more adequate manner. These tools and instruments need to analyze the non-sustainability symptoms at the systems level in relation to their deeper driving forces; they need to recognize and monitor early warning signals of non-sustainability patterns, in order to disentangle the short-term fluctuations from the long-term slow wave patterns; and they need to evaluate the sustainability impacts of strategic policies at different scales.” (Rotmans 2006, p.7)

As Dr. Rotmans describes, sustainability action today is hindered by non-unified philosophies only solved by updated approaches to identify, confront, and dispatch resource challenges presented. Actions are only relevant if implemented prior to irreversible resource damage, which emphasizes the importance of efficient decision-making. Effective strategies should then be based on comprehensive and continuous evaluations based on a platform where comparisons can be made, and application of identified best practices quickly becomes clear to enable greater sustainability action success.

Dr. Rotmans is not alone in his perception of need for a practicable, comprehensive framework and the gap he describes in currently available tools. A review of existing frameworks indicates that approachable, actionable, and adoptable tools are available, but not as a single comprehensive tool. As a result, community efforts are then reactive to particular circumstances and participants rather than choreographed for ongoing resource sustainability.

Global organizations recognize these decision-making tools are critical enablers for sustainability success, and respond by investing in research and socialization of framework solutions. As the World Commission on Environment and Development (WCED) noted in its 1987 report, "traditional forms of national sovereignty are increasingly challenged by the realities of ecological and economic dependence. Nowhere is this more true than in shared ecosystems in 'the global commons.'" (1987, p. 261 note 1) This sentiment is recognized on a global scale and demonstrated by the multitude of international organizations chartered to assess resource sustainability (the World Bank, Office of Economic Cooperation and Development (OECD), Intergovernmental Panel on Climate Change (IPCC), and others) for countries and regions worldwide. Collectively, they have great influence on policy to direct human behavior, resource strategy, reviews and actions. However, in these broad applications toward specific resource sustainability local action may become disjointed and ineffective as no universal decision-making framework is currently applied.

A wide range of participants engage in resource sustainability strategy on a daily basis and outcomes have been shown to fall short of fully implementing a sustainable solution. The discovery or development of a philosophy and toolset to promote sustainable decision-making could prevent ineffective policies and actions often the result of distraction and myopic thinking. (Ostrom 1990) In this

absence and to the detriment of humanity, reactive decision-making without a standardized framework hinders holistic sustainability advancement through structured strategy development and meaningful comparisons across local applications. (Ostrom 1990) The result is limited consideration of resource sustainability factors and diffusion of best practice which can culminate into misdirected effort, frustration, and further risk to resource availability.

A principal concern of non-standard approaches is that even though they can result in beneficial outcomes, they may simultaneously and inadvertently create negative interactions. Positive interactions govern the importance of an effective sustainability solution, and certainly promote its use; equally important, an option that is well marketed but with poor sustainability performance can destroy value. Gains and losses can then be amplified based on the initial sustainability decision and subsequent player behaviors. Consider increased solar adoption as an example of additive effect: Solar energy produces no emissions resulting in cleaner air, which in turn promotes increased solar efficiency. Similarly but in a destructive scenario, increased adoption of contaminating technologies creates 'death spirals' that result in decreased efficiency for all generation technologies. An example is a coal-fired power plant that contaminates the air, and results in less efficient combustion which reduces usable sunlight and solar availability.

Decision-makers exist across all levels of the resource use chain, and successful resource sustainability action requires participation by these individuals. The proposed ISDMF reaches beyond traditional economic considerations of supply and demand theory to incorporate a myriad of other factors that affect sustainable resource management success. This research defines, describes and tests a framework designed as a standard platform to facilitate the development and execution of resource sustainability initiatives that engage community participants and accelerate optimized initiatives.

1.2. Research Questions

Resource sustainability improvement is greatly influenced by society's ability to make effective decisions and collectively take action. To insure that decisions and actions are appropriate, current frameworks applied to sustainable decision-making must be evaluated to confirm that they foster

efficient and collectively adopted sustainable solutions. Several research questions surface with this evaluation:

1. Does a framework exist to facilitate sustainable decision-making and subsequent action?
2. Considering prior sustainability frameworks, what gaps exist and how can those gaps be addressed by an integrated framework based on established behavioral, economic, and technological philosophies?
3. What alternative framework enables comprehensive resource sustainability assessment?
4. Is the proposed Framework effective at identifying areas of opportunity and action across a resource management chain?
5. How can the availability of a new, proven framework contribute to effective and efficient sustainable decision-making?

1.3. Proposed Methods and Initial Proposal Results by Research Question

1.3.1. Does a framework exist to facilitate sustainable decision-making and subsequent action?

For hundreds of years, humanity has actively documented and worked to implement sustainability theories to optimize resource use and understand uncertainty. As with any science, attempts to present frameworks often remain dominated by the discipline from where they originate, be it environmental science, engineering or economics. (Todorov and Marinova 2009, p. 1218) By their nature, these attempts can fail to consider holistic perspective and are geared toward a specific group or application. As a result, community members outside the focused group may not engage and prescribed sustainable actions and benefits may not be realized.

A common misconception within industry and policy groups is that sustainable action is strictly driven by market economics, and that efficiencies in technology and subsequent behavioral adoptions create self-sustaining investment opportunities. This view is well publicized through the groundbreaking work by Adam Smith with his concept of "A Invisible Hand" attributed to his 1776 publication The

Wealth of Nations. Smiths work focused on the importance of market dynamics to postulate that as markets mature, interaction between buyers and sellers intrinsically improves the Quality of Life for society. Smith formalized the concept that competition between buyers and sellers for increased profit and market share eventually results in improved product offerings at increasingly competitive pricing. (Smith 1776, Book I, Chapter 7) As a corollary to Smith's original work, environmental application of this theory could postulate that, as resources become scarcer and perceived as more important in the public consciousness, societies will respond and invest to arrive at more sustainable solutions and act.

'A Invisible Hand' rings true in concept, but the science of sustainability is not completely governed by this basic relationship alone. While "A Invisible Hand" remains central to economic theory, it faces shortcomings when applied to contemporary behavior and resource sustainability. In particular, decades of academic study have shown that Adams' paradigm suffers from three principle concerns when assessing sustainability strategy: (1) latent environmental impacts also termed 'soft costs', (2) time needed to provide beneficial impacts to the greater community, and (3) resource scarcity. With these modern constraints, one could extrapolate that as depletable resources become more scarce, the concept of an 'Invisible Hand' migrates to a broader application where society is not only concerned with the product availability and price, but more availability of Quality of Life improvement at any price, otherwise known as Perfect Inelasticity.

To Mr. Smith's credit, these elements were not so concerning in his day prior to the Industrial and Technology revolutions. At that time, economies were largely agriculture-based and contained within smaller, close-knit communities. Innovation was quickly adopted across smaller numbers of participants which allows more immediate and direct observation of technological or behavioral advancement by the community. In addition, population density was much lower and resource delivery infrastructure was smaller and simpler than today.

Resource limitations are ever more critical and apparent with rapid human expansion over the past two centuries and resultant increases in resource consumption and dependence. Modern societies are generally not afforded the luxuries of unlimited time, poorly executed analysis, or sporadic implementation when striving toward sustainable resource management. With these increasing risks, we

must carefully and comprehensively consider alternatives to increase the sustainability of resources. Again, this concept is publicized in modern academic studies which highlight inconsistencies when applying 'Invisible Hand' theory to resource sustainability, often citing supply-demand economics and commodity depletion externalities as impetuses actually creating market failures. (Diamond 2011)

Rather than pure supply-demand economics, resource management frameworks are instead governed by a relationship of nature or resources as the most significant force, encompassing economics, with both of these fundamental factors determining Quality of Life. Posed alternatively, without resources economies will fail, and humanity will suffer. Eduardo Giannetti da Fonseca published this concept in his 1993 book Vícios Privados, Benefícios Públicos? A Ética na Riqueza das Nações. The concept is summarized in the following figure from his work (Todorov 2009, p. 1220):

Figure 1.3.1.1: A buffer view of the global system

With this recognition of factor relationships, interplay exists between these nested factors driven either by anthropogenic or natural processes. As an example of de Fonseca's concept, if one’s environment is unlivable (cannot breathe the air, for example) the situation is unsustainable, regardless

of economic condition or policy. However, if the nature condition is excellent (food is abundant, and environment is pristine) economics may represent low importance to Quality of Life. An effective resource sustainability decision-making framework must contemplate these interactions and provide users with strategic considerations to select the most viable and successful alternative. This general idea of high level factors of Humanity, Economy, and Nature presented by de Fonseca can be viewed alternatively as a dynamic system, which is illustrated in the following figure 1.3.1.2 reproduced from the works of Robert W. Kates and Billie Lee Turner II (2011, p. 7):

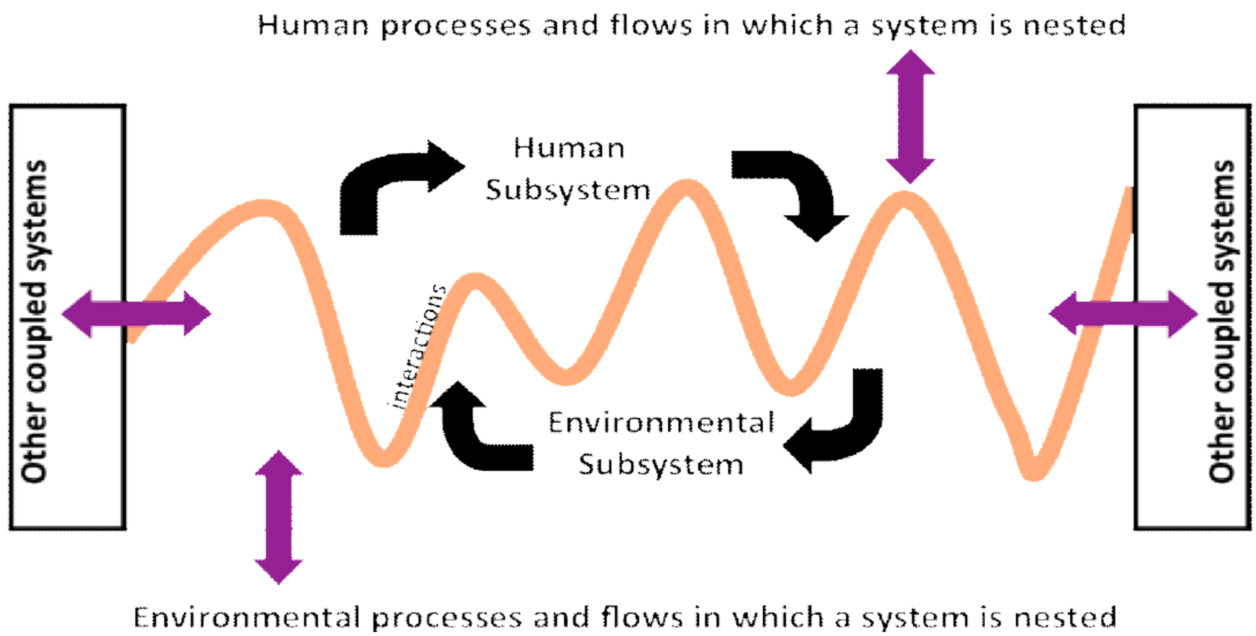

Figure 1.3.1.2: The coupled human-environment system overview

Dynamic interaction of humans with environment and coupled systems, as shown above, can quickly expand as specifics are integrated into the sustainability evaluation for any given resource, demographic, or geographic location.

In the following extrapolation of the base coupled human-environment concept, system assessments undergo a rapid expansion from the general case to a complex and unwieldy collection of

sustainability factors. As a general example, when factors are added the basic concept quickly evolves into a nearly unmanageable representation for quantitative, actionable study and resolution:

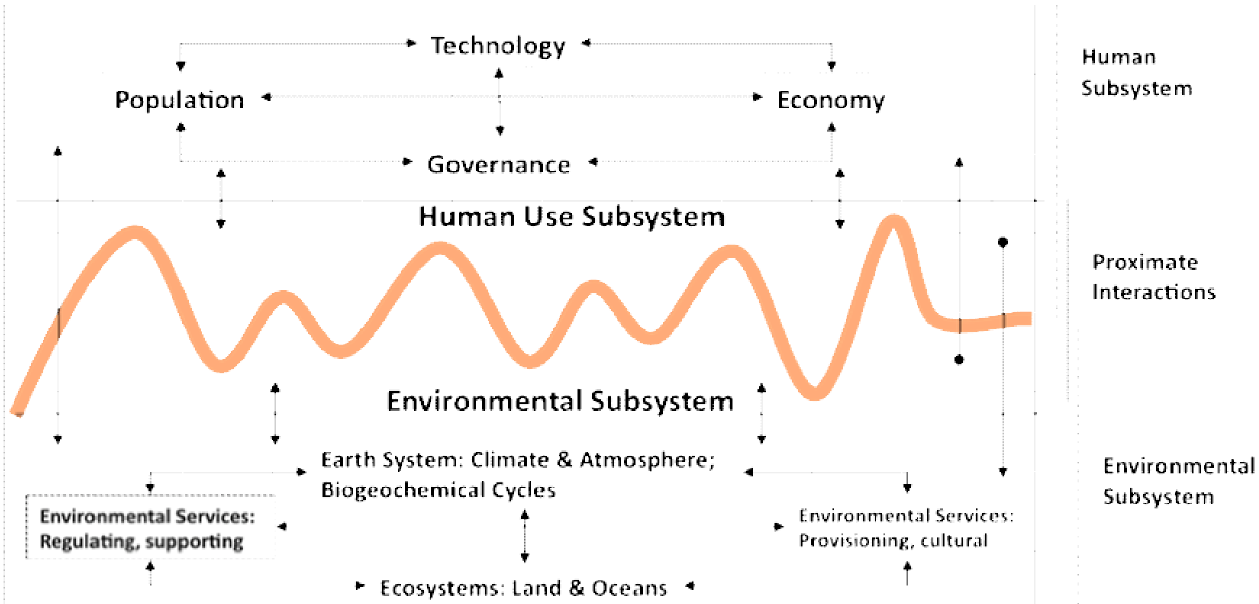

Figure 1.3.1.3: Inner-workings of Coupled Human-Environment Systems (Kates 2011, p. 7)

This example of rapid expansion of a basic view illustrates the complexity and application challenges within sustainability framework application. As diversity of participants in the system and sustainability decisions are considered, a need emerges for a simplified, applicable, and actionable check list of considerations that can be widely accepted and applied. This general example also demonstrates that a simplified approach must provide sufficient specificity to allow any participant in a resource delivery chain to understand sustainability decision opportunities and act.

Available frameworks regularly remind the user to consider long-term impacts of a decision in their strategy. A paramount study published by the United Nations (UN) in 1987 is often cited as a defining document of the "Future" sustainability concept. The Report of the World Commission on Environment and Development: Our Common Future issued by the Brundtland Commission summarizes sustainability and clarifies the conclusion of long-run consideration:

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts:

- The concept of 'needs', in particular the essential needs of the world's poor, to which overriding priority should be given; and
- The idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs." (WCED 1987)

While this is not the first attempt to define sustainability, these descriptors provide a platform for a framework vision and highlight the fundamental framework consideration of 'long term' outcomes.

These three bases of framework development, as clarified by the works of Giannetti, Kates, and the UN Brundtland Commission, can be observed in all sustainability frameworks catalogued as prior work. To summarize, identified frameworks first consider the nexus of nature, economics and humanity, then approach a means of communicating strategy elements and actions for long-run sustainable outcomes.

Prior Work is organized under categories as developed by Vladislav Todorov and Dora Marinova in their July 2009 work "Models of Sustainability". Their approach summarizes that four major categories of frameworks exist when considering sustainability assessment and decision-making frameworks: Pictorial, Quantitative, Physical, and Conceptual (Todorov and Marinova 2009). While those four categories offer a means to separate and analyze prior work, other examples were identified that prompted the expansion of their assessment.

Five to ten examples for each Todorov and Marinova category were identified and critiqued to demonstrate category descriptions with practical applications which enables relative comparison of approachability, actionability, and adoptability characteristics. The Literature Review section presents select Framework examples for each type, and a summary of identified prior work categories is included in Appendix A for reference.

1.3.2. Considering prior sustainability frameworks, what gaps exist and how can those gaps be addressed by an integrated framework based on established behavioral, economic, and technological philosophies?

Prior framework assessment and implementation results suggest that gaps exist within available resource management decision-making frameworks. A clear identified gap in existing framework use is that player participation is limited by the relative absence of comprehensive and structured assessment tools. (Rotmans 2006) Without approachable and actionable methods, participants are obligated to rely on prior knowledge and experience for policy and investment actions largely based on individual perspectives. These decisions are subsequently dependent on the level of individual knowledge and skill, become subjective, and may ignore broader impacts. At a most basic level, frameworks can be divided into two categories of more simple approaches that apply pictorial and/or conceptual means to convey ideas (as in the Gianetti case presented earlier), or very quickly jump to complexity and uncertainty as was shown in the Kates example. These phenomena can be described by two main observations of existing Simple and Complex framework intention and design:

a. Simple frameworks limit application by not addressing specific resources or players as a means to stimulate action. In that sense, they do not offer clear actionable solutions toward sustainability except in cases where a baseline is measured and reduction goals are established. However, Pictorial and Conceptual approaches are popular and effective to quickly socialize general sustainability concepts and gain acceptance.

b. Complex frameworks are excellent solutions for those involved with their development, but may be too complicated for ready adoption by anyone outside of the originating group. (Rogers 2003) They are also hindered by encompassing many resources, factors, and respective variability. Discussion using a complex framework stimulates dialogue, but unfortunately complexity and specificity to a particular group may limit sustainability strategy success.

From these general observations, effective frameworks for resource sustainability decision-making must be (1) approachable, (2) actionable, and (3) widely adopted to provide sustainable benefits. Review of prior works, organized per the structure of Todorov and Marinova and supported by others, suggest that these three elements are not wholly observed in a single functional framework. A summary of prior and existing frameworks for gap assessment must be performed to ensure that clear sustainability science advancement is achieved. With the three core elements of a viable framework identified and combined with a categorization method (Todorov), a broad spectrum of framework examples were compiled from public domain research. Each category was assessed based on approachability, actionability, and adoptability for comparison. As with any public domain research, the possibility remains that other viable frameworks do exist, but initial review indicates that effective and efficient framework availability is limited or simply not available.

Each basic category as defined by Todorov, et. al. was evaluated across normalized criterion for relative impact for given type and rated. As illustrated in the assessment summary in figure 1.3.2.1, published frameworks approach but do not achieve the ideal sustainable approachability, actionability, and widespread adoption region of utility when evaluated individually. This observation suggests that gaps exist among current offerings to offer a framework as a standard template for users to engage in resource sustainability decision-making.

Three major outcomes emerged from this initial assessment: (1) Some categories are actionable, but only by groups involved in their development limiting approachability and adoptability (as indicated by bubble size), (2) many categories are approachable and adoptable but do not clearly communicate action, and (3) none of the identified categories or examples provide a framework that is comprehensively approachable, actionable, and adoptable for resource sustainability decision-making.

This work suggests that a new Framework could offer value to sustainability science, as summarized in the following figure 1.3.2.1 and expanded in Appendix A.

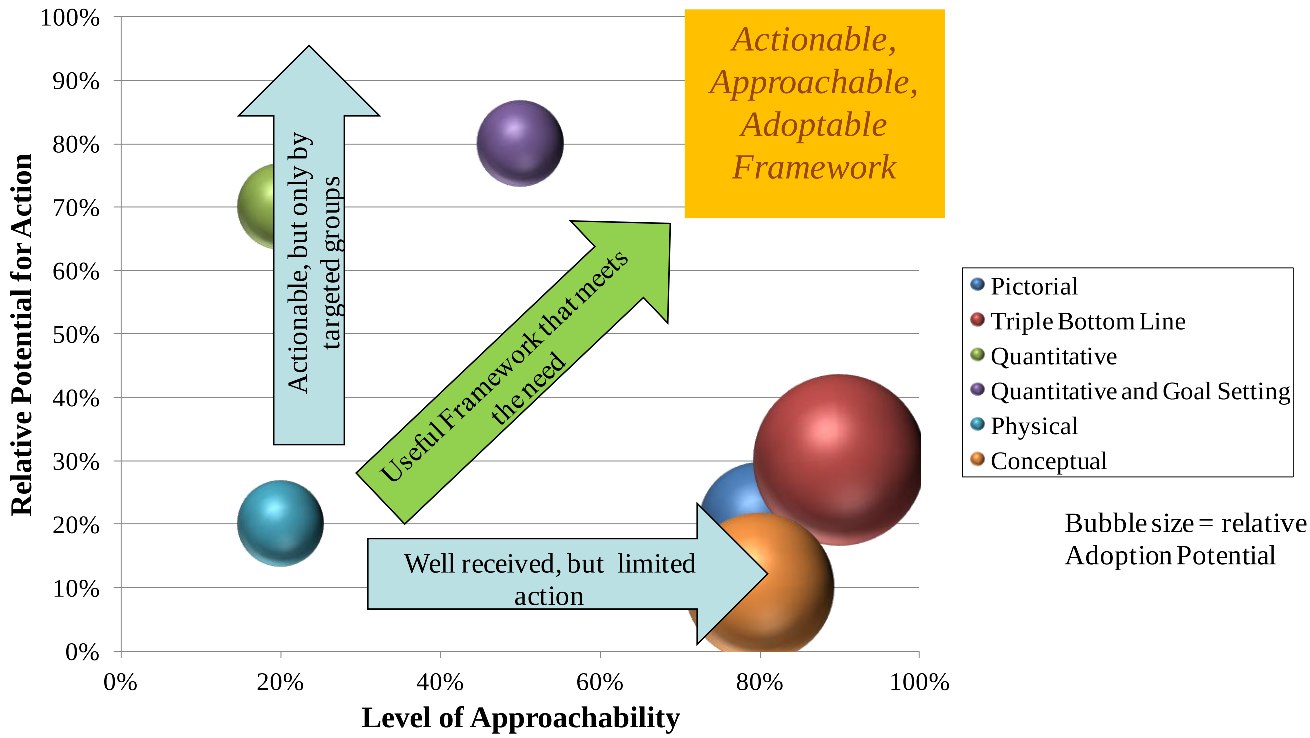

Figure 1.3.2.1: Comparison of Relative Approachability, Actionability, and Adoptability of Frameworks

Each observed framework provides value toward resource sustainability, but none was able to comprehensively provide single source development to embrace as a standard. The vision of this work is to close this observed gap, and offer a standard framework to promote widespread participation toward sustainable action through awareness and education.

Gaps in available frameworks can be closed by considering established theories and methods that contribute to sustainable resource decision-making. Any supporting theories should already be widely recognized and accepted to ensure the Framework itself will be embraced. In addition, as was observed with adopted frameworks such as Pictorial and Conceptual, an integrated framework should have an appropriate blend of visual process description combined with toolsets that help determine and convey specific action. Any developed framework must consider key contributors that affect resource use and offer users with a broad perspective encompassing human behavior, the environment, technology and associated economic factors influencing long-term resource sustainability. Finally and most challenging,

the framework should be general in nature to promote a standardization of application that facilitates systemic comparisons to identify 'best' and 'worst' practices.

This framework assessment only indicates the performance of the four standard framework types as defined by Todorov and Marinova, with extension of two base types for a total of six. Another category discussed in the Literature Review is the Combined approach, where two or more framework types are fused. The benefit of combination occurs when identified value and deficiencies of elements are assessed, and the product of analysis is a more complete and effective solution (Kolb 1975), The example most aligned with the ISDMF is the Sustainability Framework combined approach offered by the National Acadamies and published by the Organization for Economic Co-operation and Development (OECD). Their approach is very similar in structure and content to the ISDMF, and comparison of the two indicates specific gaps requiring closure. Details are available in the Literature Review, section 2.1. Combined Approaches.

1.3.3. What framework enables comprehensive resource sustainability assessment?

In the preceding section, gaps in currently available frameworks and toolsets were identified and described. The practical development to close the gaps requires assessment of core elements of sustainable resource decision-making that promote effectiveness, efficiency, and widespread adoption. Vision and Goals are critical elements as is actual adoption by a given community and each is incorporated in the ISDMF.

Development of a novel decision-making framework first requires a definition of Sustainability. Merriam Webster online does not list Sustainability as a word, but does list Sustainable as an adjective in use since circa 1727. Merriam defines Sustainable as "(1) capable of being sustained, and (2)(a) of, relating to, or being a method of harvesting or using a resource so that the resource is not depleted or permanently damaged <sustainable techniques> <sustainable agriculture>, (b) of or relating to a lifestyle involving the use of sustainable methods <sustainable society>". For ISDMF application, this definition of Sustainable covers key concepts of methods, resources, depletion and damage, but is narrow in scope by basing the concept on physical resources. Sustainability includes natural resources, but expands beyond that specific topic to represent a state of being termed "Quality of Life" in this work. In that

sense, all elements of the Merriam definition are included with an extension of application to establish the word Sustainability as a noun with the following definition for use in this work: "A state of maintained or improving Quality of Life today and in the future."

Several concepts aggregate to converge on this definition of Sustainability. The Bruntland Commission's assessment outlined several components necessary for a sustainable solution. First, society has to determine a need and define it as a decision opportunity. Second, technological and economic constraints should be evaluated to optimize sustainable solution migration ' direction' and 'velocity' to meet a need. Lastly, society's investment in these potential sustainability 'game changers' is reflected in the amount of effort dedicated to accelerate the migration or adoption of an emerging innovation and make it sustainable.

The need can be projected to an 'Ideal Case' for a resource that may not currently be possible because of technological or economic constraints. However, a sustainability vision for a resource is driven and described by an 'ideal'. Development of a Vision must incorporate short- and long-run perspectives to gauge action and stimulate interest and participation in the sustainability strategy. A strategy that reinforces active, community wide participation in sustainable measures can accelerate the progression along a sustainable trajectory or vector toward the ideal.

In a perfect world, customers seek readily available, clean, and in a best case free resources to best manage their Quality of Life. International, Federal, State, and Local governing bodies worldwide work to promote behavioral or technological solutions to more rapidly approach the ideal state, and fund those initiatives through taxation, regulatory demands, and management of delivery costs.

As illustrated in figure 1.3.2.1, Consumer Need can be considered a space without boundary or infinite as advancement creates luxury and convenience. Society can then envision current ideal states and make economic, political, and personal decisions to most effectively migrate to a more ideal case. As consumer need and willingness to participate converge on sustainable policies and actions, they accelerate the business environment for innovation adoption. (Rogers 2003) This concept becomes particularly important as new ideas and solutions displace incumbent practices to expedite convergence to an ideal solution.

From history, technology dislocations exist and facilitate acceptance of innovations both physically and behaviorally that benefit society when benefits are clearly and comprehensively known. A corollary to these points is that innovation can positively affect society, and technology advances are best communicated through education and promotion. (Rogers 2003)

As these actions advance, frameworks can be applied at any time throughout the Need / Technology synthesis and progression. From the United Nations report (WECD 1987), each point of sustainability migration should continuously be assessed, which implies a measurement and monitoring component in a comprehensive framework. In this way, the trajectory of innovation migration can be optimized based on current state positioning and actions to ensure efficient and effective sustainability progress in the future.

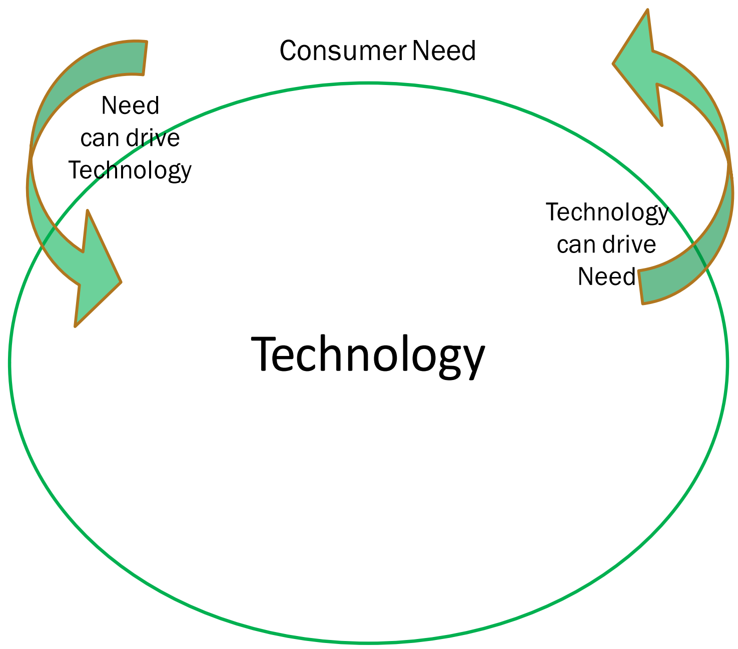

Figure 1.3.3.1: Market Dynamics Considering Customer Need and Technology

With this general definition of possibility and 'Ideal Case' trajectory, and assuming prudent advancement, resource participants can determine several questions and actions. A framework emerges based on logical questions that motivate individuals to learn more about available tools and concepts already published, as well as theoretical concepts necessary to understand the concept of sustainability and its longer-term impacts. As an affected community, the acceleration of the trajectory of ideal case resource management activities requires a logical, intelligent, and efficient method in the form of a decision-making framework that can be applied by all citizens.

The summary of prior frameworks affords insight toward a troubling conclusion: A plethora of tools are available to best guide sustainability decision-making, but none have been identified to provide participants with a comprehensive and clear means of assessment that is approachable, actionable, and offers the possibility of widespread adoption. Experts across academia, industry, and policy fields continue to be challenged by this reality and apply single and combined approaches, or invent more as they work to tackle sustainability challenges.

This research offers a novel approach based on prior work, and strives to incorporate recognized sustainability strategy and theory to provide users with a new framework to more quickly assess current state and arrive at sustainable resource use options. This focus and supporting research can more expediently notify participants of long-run sustainability risks based on their immediate actions, and provides them with a toolset to more rapidly understand if immediate actions are most beneficial today while offering sustainable future outcomes. Stated alternatively, the ISDMF is designed to be a 'checklist' that participants can apply to advance clear sustainable strategies and actions across varied cultures, locations, and resources.

1.3.3.1.Integrated Sustainability Decision-Making Framework Overview

The ISDMF is a structured approach based on available economic and technological options, risk mitigation techniques, diffusion of innovation, and ongoing assessment and continuous improvement theories. It is primarily based on two player game theory to assess motivational patterns, technology, and economics. Base two-player game theory is expanded to a more comprehensive, supported decision-making Framework as synthesized from recognized contributions by Smith, Lloyd, Hardin, Porter, Ostrom, Senge, Rogers and Deming beginning from the 18th century to present. These core elements combine to create a theory structure, which is illustrated in the following hierarchy, figure 1.3.3.2:

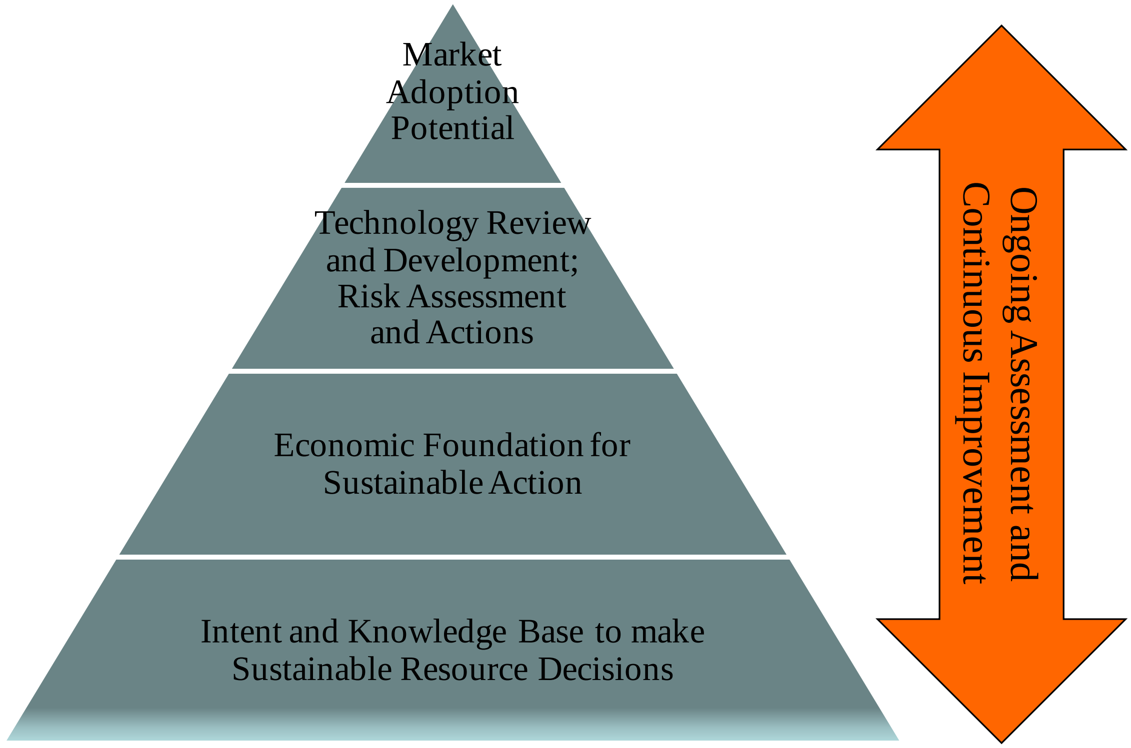

Figure 1.3.3.2: Integrated Sustainability Decision-Making Framework theory structure

Most basic to the establishment of a strategy is the knowledge and awareness of the Community to recognize a need for action. This realization initiates the application of the ISDMF and represents the base of the theory component pyramid. The second level is economic availability to enable option implementation. This enables the third level which is to assess technology positioning and development options with inherent application risks. The fourth and final level or 'step' in the decision-making hierarchy is adoption of the strategy (also known as 'Diffusion of Innovation')which is the peak of the theory pyramid and represents embracement by the affected Community. Across and influencing each pyramid level is Measurement and Continuous Improvement activity. Each of these elements work in conjunction to form the theoretical basis of the ISDMF as philosophically illustrated in Figure 1.3.3.2.

With the structure of a philosophy established for Framework development, a more actionable and adoptable process view can be derived from these five major elements, organized in an execution

sequence. The Framework process view helps users standardize strategic decision-making and allow coordinated and comparative assessments. Each participant within the resource use chain can apply the ISDMF sequence to better understand optimal resource sustainability alternatives and take action. Note that not all steps may apply to all participants, but the intention of the ISDMF is to augment the level of education and awareness in Sustainability Science for each participant by offering a template of integrated, proven theories that streamline and promote standardized, sustainable resource decision-making.

The following process flow outlines major Framework elements and defines the specific components within each to guide sustainability considerations in a logical order. This decision-making process is designated The Integrated Sustainability Decision-Making Framework, and is presented as figure 1.3.3.3:

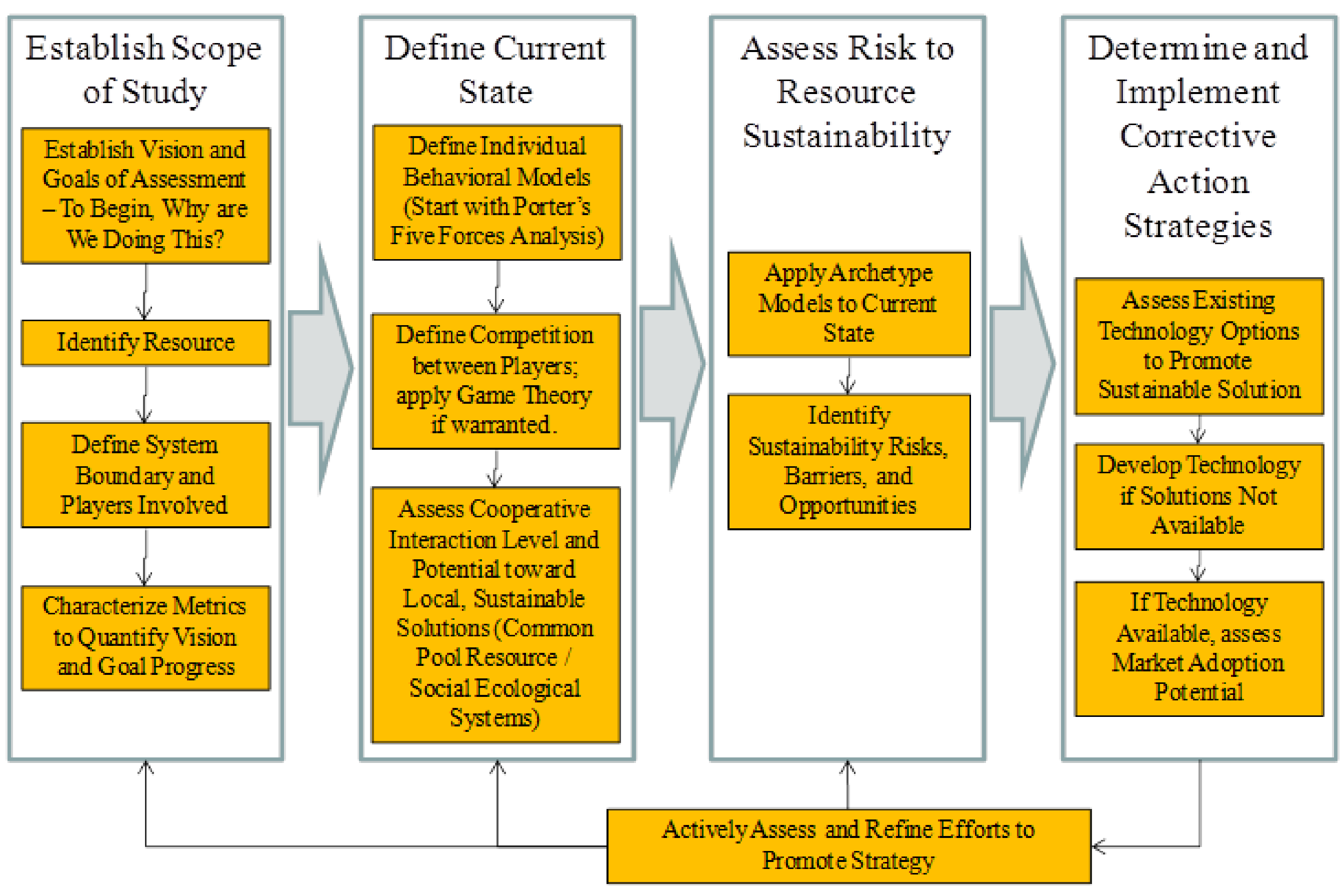

Figure 1.3.3.3: Integrated Sustainability Decision-Making Framework process view

Background information to further support and expand the theories is offered in the Literature Review and Results sections.

With the principle relationship of integrated theories presented, a more detailed description of each is provided in the following sections. Per the process flow, the five components of the Framework, in order, are:

1.3.3.2.Establish Scope of Study

As with any undertaking, efficient development and execution is dependent on participant ability to understand the rationale for action and the scope of effort. Through this visioning and goal setting process, users can apply the ISDMF to establish a resource sustainability strategy and set of actions. The following sections guide the user through the Scope of Study elements as a first step in the ISDMF strategy development process:

Establish Vision and Goals of the Assessment

Concerned community members invest time to assess their respective values, opportunities, and goals to determine if they are prepared to act approach optimal sustainability solutions. Long-term benefit requires consideration of holistic perspectives for any given need, and identification of the resource use required to preserve current Quality of Life and for generations to follow. Concern and investment is required to be educated and aware, and that knowledge can be used to construct a vision and sense of goals toward resource sustainability.

For many, the 'long-term' does not extend beyond today. Regularly community members are captured by immediate needs and make spontaneous decisions out of obligation or convenience. Reactive posturing may provide comfort, but not consider the importance of depleting or worsening resource positions. Each day that passes, society is granted an opportunity to improve; but, may overlook opportunities to set new behaviors and investments to create a better tomorrow out of convenience. To engage in resource planning, communities should consider: Can efforts today create a

better future, or are controlling factors beyond reach? As a parent, will children celebrate an improving Quality of Life, or shun poor decisions today for immediate, myopic benefit?

Sustainable decision-making requires commitment, and in tandem a well crafted vision and set of intended goals. If these elements are not defined, any further analysis or action likely will not be successful.

Identify Resource

Clear definition of the resource under review is the next core-determining factor of the ISDMF, as all other factors hinge around this critical decision. Sustainable decision-making typically impacts resources deemed (1) rivalrous, and (2) depletable, meaning that users of the constrained resource have options to control use and availability. Unfortunately, often effort surrounding selection of a resource occurs once concern has escalated and resource usage is deemed unsustainable. Instead, users should consider the ISDMF as a proactive tool, intended to provide maximum benefit should it be applied before sustainability concerns become critical and cooperative resource use is contentious. The lack or increased price of a resource will illicit widespread socialization of the need for sustainability strategy and respective action. However, at that level of resource stress, objective sustainability decision consensus will be more challenging and players may not willingly participate in holistic improvement. For example, perceived time constraints may limit the availability of viable options which reduces the range and effectiveness of more sustainable action. Overriding and critical to the ISDMF effectiveness, users either proactively or reactively identify and engage to affect specific resources worthy of sustainability consideration.

Define System Boundary and Players Involved

Sustainability analyses can be very broad when viewing macroscopic impacts to a given environment. In step, boundaries must be set to manageable, localized geographic ranges where decisions of the players within that given locale have effect. As will be covered in the Literature Review

under cooperative management, systems are affected by internal and external forces and boundaries must be set to enable determined strategies and actions. (Ostrom 1990)

Framework success also requires the intelligent application of ‘participant’ or ‘player’ definitions. (Rogers 2003) To enable efficient use of game theory, clear definition of players competing for a given resource must be established. Grouping of players and resultant rivalry is often not immediately obvious when considering complex resource management systems. For example, a defined 'player' may actually represent a wide range of participants under a single grouping (customers that are wealthy or not, educated or not, etc.). This variation or heterophily within player definition can influence a technology or service innovation for community adoption. (Rogers 2003) Grouping strategy is of critical importance as viable sustainable strategy analyses require that a minimum of two general players (or more) be established to recognize competition. Otherwise, ISDMF approachability is diminished and clear actionable results may not be determined as a cooperative environment of idea sharing across a resource delivery chain. And, rarely will resource systems worthy of ISDMF application be so direct as to only have a single player. . These grouping and interaction concepts are reviewed in depth in Rogers' research, and are expanded in the Literature Review section.

Characterize Metrics to Quantify Vision and Goal Progress

The adage “You can't manage what you can't measure” rings very true when applied to sustainability strategy and management. This ISDMF component is critical as an ongoing process to continuously improve resource sustainability strategy effectiveness. Once the prior steps are completed to establish Scope of Study, this planning step should be exercised to clarify resource sustainability variables affected, and if action is taken, to establish measurement strategies that confirm sustainability goals are actually being achieved.

Sustainability decision-makers face a formidable challenge: Quantifying Quality of Life elements can reach into 'soft data' which may not be conducive to measurement. Consider that many resource factors are well aligned to measurement such as cost, energy consumption, water usage or localized air quality among others. However, as well recognized by William Edwards Deming (October

14, 1900 – December 20, 1993), when considering impacts of education, awareness, behavior, or social justice regularly “the most important figures that one needs for management are unknown or unknowable (Lloyd S. Nelson, director of statistical methods for the Nashua corporation), but successful management must nevertheless take account of them.” (Deming 1986, p. 121) Independent of this inherent and identified complication when assessing sustainability strategy and action, the ISDMF user must make an initial effort to clearly define quantitative or qualitative means of assessing strategy performance to vision and goals.

1.3.3.3.Define Current State

With a playing field set by applying the Scope of Study element of the ISDMF, Current State is defined by strategic and economic interactions between the players involved in the sustainable decision-making process for the selected resource and player set. In the Framework, the base economic approach is defined at three levels: (1) Individual Participant, (2) Game Theory between Players, and (3) Level of Cooperative Action.

Individual Participant

The first consideration to Define the Current State within the ISDMF is to assess the current situation and perspectives of each individual player. Per the process flow, and as a starting point for this element of the ISDMF, individual behavior is initially assessed by applying Michael Porter’s Five Forces Analysis. Porter's work is selected as a widely respected and applied approach to evaluate strategy, and is one of the more direct and insightful means of gaining individual motivational pattern understanding. Porter's theory is included in detail in the Literature Review section (Porter 2008, p. 27).

Initial market assessment requires a starting point, and as was stated by Geoff Colvin, Senior Editor-at-large at Fortune Magazine, business strategists "Generally without knowing it, they -- we -- are speaking the language of Harvard's Michael Porter, the most famous and influential business professor who has ever lived." (Colvin 2012) Certainly, additional approaches can be added to further define the behavior and positioning of all identified players, but Porter's Five Forces analysis offers the user a

respected reference to build strategy. Porter's analysis can assist the ISDMF user to analyze expected player actions and interactions based on current positioning and options as individual participants in the 'Game'. As was discussed in Define System Boundary and Players Involved (Section 1.3.3.2), these ‘individual’ assessments are not designed to represent a specific person, but rather represent a grouping of similar participants to represent an entity deemed ‘player’ for ISDMF consideration. The collective action of these unique participants sets, grouped based on similar motivations and behaviors, must be considered individually to allow community diagnosis of a resource sustainability concern. (Rogers 2003)

Game Theory between Players

Game Theory is next applied to consider how each of the defined, individual players interact. In the case of resource management, Two Player game theories are selected as a demonstrative basis to analyze the interaction of individual players when considering resource use. Many game configurations exist and can be applied for specific resource competition scenarios. However with average resource management schemes more regularly two, or in some cases more unique sets of ‘players’ can be defined that face inherent risks of working toward (1) individual best interest for short-term gain, or (2) collectively enhancing long-run resource outcomes for players and the community as a whole. Within these approaches, two operational modes or levels can be set: Complete player knowledge, and conversely incomplete knowledge. (Ostrom 1990)

The use of Game Theory implies competition, and inherently when a resource is placed in an increased demand and constant supply, each player must be cognizant that resources can be economically or even physically constrained when a single player attempts to exploit relative to others. A key lesson derived from game theory application, and occasionally in conflict with Adam Smith’s theory, is that if any single player attempts to enhance their respective position by leveraging a resource beyond equitable distribution, outcomes could potentially arrive at depletion and the detriment of all. Phrased alternatively, if a cooperative approach is not embraced and adopted by all involved players,

resources can be unsustainably consumed and participants may suffer decreased utility or exhausted availability over time.

Level of Cooperative Action

Individual and Game Theory analyses assume competition between players, and are applied in the ISDMF to assess the expected behavior of any individual or collection of participants as a group when placed in a competitive environment.

One factor potentially overlooked in these analyses is the impact of cooperation in localized settings. Resource sustainability decision-making must not only consider benefits and challenges of individual player motivations, but also incorporate the sustainability potential of open cooperation. Within the Framework, deference is first given to individual player actions that create adversarial play as they are most often applied in resource decision-making as competition. However, strategy for sustainable solutions would be impossible if users do not consider the benefits of full disclosure and cooperation.

These localized, cooperative concepts were studied by Elinor Ostrom who created an immense body of research to better recognize and understand respective impacts to resource management strategies. Her findings reinforce the need for cooperative theory integration into the ISDMF. Ostrom contends, and has proven through empirical study, that if competing players in a system requiring sustainable action are allowed to locally guide strategy through good faith cooperation, all players are more likely to collectively receive long-run benefits and arrive at more sustainable resource solutions. Ostrom's selected theories are included as the final category within the Current State element of the ISDMF.

Ostrom gained international recognition with the publication of her work Governing the Commons: The Evolution of Institutions for Collective Action in 1990, where she challenged the assumption that shared use of resources inevitably leads to abuse by an individual and eventual tragedy for all. She demonstrated through observation and study that communities can in fact use resources sustainably when based on a set of clear mutually accepted rules. Generally, the rules surround concepts

of disclosure, and penalties levied against abusers or 'free riders'. (Ostrom 1990) Her work highlights the possibility that while competition may limit sustainable action, its adverse influence can be offset through cooperative intent of the players. Of key importance in her work is the idea that these controls must be locally determined and managed within established boundaries to adapt to dynamic yet specific circumstances. These concepts can be summarized as "self-organized" collective action, which confirms that a third and possibly superior mode of governance by affected populace may exist outside of state or market controlled environments. Mrs. Ostrom terms her theories Common Pool Resource (CPR) (Ostrom 1990) and Social Ecological System (SES) management (Ostrom 2009), which are expanded upon in the Literature Review of this work.

As with any cooperative strategy, the affected community must be engaged. (Ostrom 2009) If local participation toward sustainable solutions is widespread, collective impact ensures adoption and creation of value for the community. In addition, a community only becomes active in the decision-making process when they are educated and aware of the risks and benefits presented. (Ostrom 1990) This concept is additionally supported by adoption theory, which is also termed Diffusion of Innovation science by Everett Rogers and other contributors which is discussed in more detail in the Literature Review. (Rogers 2003)

Combination of these established economic theories of individual, competitive, and cooperative player behavior are used within the Framework to define Current State. Sequencing in this order provides a standard approach regarding core decision-making perspectives of each player, and completes the Define Current State element of the ISDMF.

1.3.3.4.Assess Risk to Resource Sustainability

Previous sections arm the sustainability decision-maker with a clear understanding of purpose, scope, and current state of play for a given resource. At this stage of the ISDMF process, consideration must be given to risks and potential root causes to a sustainable resource management regime. The third ISDMF step considers risk and actionable play within the economic and behavioral assessment by applying Archetype concepts. Problem and solution assessment can take many forms, and may be

plagued by tangents and diversions. Archetype theory assists the user to identify risks generally observed in prior management efforts for specific types of organizations and environments. (Senge 1990)

System Archetypes

A toolset that allows a resource manager to assess, organize, and address concerns is the application of System Archetypes. Merriam Webster Online defines Archetypes as “1: the original pattern or model of which all things of the same type are representations or copies : prototype; also : a perfect example; 2: idea.” These 'patterns' have been studied by a wide array of academic, industrial, and policy participants and have been summarized by Peter Senge in his comprehensive work 'The Fifth Discipline'.

The Archetypes are based on observed and analyzed situations with similar causation factors, subsequent adverse risks, and established corrective actions that can be applied to a general situation to improve or prevent adverse future outcomes. Archetype theory can assist users to proactively develop resource sustainability strategies, and helps distill complex observations made from economic assessments in the first and second steps of the ISDMF. The Archetype method outlines expected interaction between players in a given scenario and can help anticipate unintentional future outcomes. Integration of this concept with the Define Current State assessment element of the ISDMF provides a 'plan of action' in response to individual and interactive motivations.

Several of the archetypes from Senge and Braun can be reasonably applied to resource sustainability management, with three core types standing above: Accidental Adversaries (Braun 2002, p. 19-21) which are applied in this dissertation methods section for the resource of electricity; and similarly but to more expandable resources the archetypes of Escalation (Senge 1990, p. 384-385); and finally Tragedy of the Commons in the case of finite and depeatable resources (Senge 1990, p. 387-388). These three archetypes are reproduced in Appendix B with a decision tree included in the Literature Review (section 2.3) for user reference.

Identify Sustainability Risks, Barriers, and Opportunities

As was described in the System Archetype section above, Archetype analysis helps ISDMF users to better understand risks to current state resource management, and highlights barriers in current resource structure and operation to improve. Archetypes are not the only approach, but provide a useful, established, and common means to begin assessment. With these tools applied, risks and barriers to sustainable action may become more apparent and potential avenues of improvement can emerge. Typically, opportunities manifest as modified behavior, processes, and technology improvements that are considered in the next section of the ISDMF.

1.3.3.5.Determine and Implement Corrective Action Strategies

The fourth distinct element of the ISDMF is the dynamic nature of technology 'enabled' sustainability options for a given resource, and to simultaneously assess the current and potential levels of adoption (also known as Diffusion of Innovation). This process step provides the Framework user with technique 'starting points' on the ISDMF 'check list' to understand local market position, sustainability opportunities, and recommended adoption actions. The result of the integration of these elements is a more complete template to address resource challenges and converge toward an ideal state of resource sustainability.

Existing Technology Options to Promote Sustainable Solution

Technology is a key enabler of resource sustainability initiatives, and presents a significant decision-making challenge. Currently, technology is a highly economic and dynamic factor subject to uncertainty and dependent on other aspects of the sustainability Framework. Technological advances may require large investments in research and development, and developers often protect efforts to make investment worthwhile. This defensive behavior can provoke economic constraints that limit widespread adoption. As meaningful intentions in technological advancement are realized, they are often greatly

influenced by the developer's immediate need to create financial 'winners'. Rarely are highly economical innovations initially released at adoptable price points.

To community benefit and dismay, technology may then be captured by the more simple economic theory as described by Adam Smith and governed by his theory of 'A Invisible Hand'. Improved technology solutions offered at ever-decreasing price points would be more readily adopted, and an improving market would be supported. The only caveat is that often optimal solutions are either in incubation or do not have sufficient socialization, also termed Economies of Scale, to fully enable sustainable alternatives. Regardless, active sustainability planners must be cognizant to best apply known technologies, economics, and adoption potential to the current range of sustainability options to enable optimized solutions. These innovations may present increased risk when migrating away from incumbent alternatives, but ISDMF application considers that participants invest effort to understand technological opportunities to better embrace sustainability.

Improved technology does not imply adoption, which is an ongoing challenge to 'Invisible Hand' theory in contemporary application. Often, best-case technologies are either too expensive to implement, remain unknown to potential adopters, or are not sufficiently available for commercialization to make them viable. Independent of these limitations, most innovative and sustainable technologies do pursue commercial intent over time and often invest appropriate levels of socialization to gain market acceptance and growth. Aligned with this concept, technological innovation and respective adoption can occur beyond the scope of immediate framework participants to better enable communication, which is assumed in the economic evaluation outlined in the Current State assessment element of the ISDMF.

A framework for long run planning must be independent of technological offerings to be viable as technology is constantly improving, but motivations and behaviors leading to sustainable resource decision-making are more consistent across technological advancements. For this reason, this work does not delve into particulars of any given technology beyond case study application for a specific resource and communities with documented, aligned, and comparable resource management options.

If Technology is Available, Assess Market Adoption Potential

The final step in the fourth element of the ISDMF is to consider participant adoption and effects on sustainability. For sustainable action to be effective, it must be embraced and adopted by the affected community to offer value. History presents many examples where beneficial behaviors and technologies are not readily embraced due to gaps in education and awareness. (Rogers 2003)

While developed sustainability solutions may offer an opportunity to improve, a community may choose not adopt and forgo potential enhancement to their respective resource position. The longer run sustainability consequence is that society overlooks beneficial options and limits migration to improved Quality of Life. In addition to overlooking sustainability solutions, partial adoption can also be limiting as innovation requires critical mass adoption to proliferate. (Rogers 2003, p. 344). Even with advantageous positioning across environment, policy, technology, and general sustainability concern community adoption may not occur. Critical levels of adoption are necessary to ensure impactful incorporation of sustainable innovations, and this barrier to sustainable migration exists because able and willing participants may not be (1) educated in the beneficial options available, and / or (2) aware of option accessibility. (Rogers 2003, p. 172)

With that premise, new ideas introduced in a resource sustainability strategy must be adopted to have significant value toward Quality of Life improvement. Everett M. Rogers (1931-2004) is a prolific contributor to the science of Diffusion of Innovation, and this introduction to the concept for use in the ISDMF is largely based on his principles and theories. Diffusion of Innovation is perhaps the most important science affecting the migration to sustainable solutions. It governs the actual effect of strategy as a measure of behavior or technology innovation adoption outcomes. Even well developed and founded behavioral or technological strategies confront the risk that they will not be absorbed by the larger community and only offer limited sustainability affect. Extrapolation can be made that the most impactful gains of an effective sustainability strategy are derived when an entire community, encompassing all players, is persuaded to be active in the effort. For these reasons, community engagement and adoption concepts are discussed in more detail in the Literature Review, section 2.4.

For Framework application and as an introduction to the topic by a respected contributor to the science, Rogers (2003) provides the following key definitions for user initial assessment:

- Diffusion - "The process by which (1) an *innovation* (2) is *communicated* through certain *channels* (3) *over time* (4) among the members of a *social system*." (p. 11)
- Innovation – "An idea, practice of object that is perceived as new by an individual or other unit of adoption. It matters little, as far as human behavior is concerned, whether or not an idea is "objectively" new as measured by the lapse of time since its first use of discovery. This perceived newness of the idea for the individual determines his or her reaction to it. In an idea seems new to the individual, it is an innovation." (p. 12)

With Diffusion and Innovation defined, a basis for Framework inclusion emerges: Sustainable solutions require adoption, and must have relevance to any solution strategy. An assumption is that if a community does not embrace a sustainability strategy, the strategy is doomed to eventual failure. With that consideration, the ISDMF includes an assessment of adoption and its implications for a given resource sustainability strategy. These concepts will be expanded in the Literature Review section, but these initial definitions and concepts create a major pillar of the ISDMF philosophy.

1.3.3.6.Actively Assess and Refine Efforts to Promote Strategy

Active assessment and refinement is critical to fully enable the ISDMF and basically any sustainability strategy This overriding process step is included to remind a user to continuously assess strategy performance by installing and monitoring metrics defined during the Establish Scope of Study and throughout Framework development and use. As was mentioned, metrics will be specific to a resource, player definition, and scope.

Definition of this element completes the ISDMF and creates a closed feedback loop within. While initially well-developed strategies can be expected to drive short run success, any long-term

strategy must continuously reassess performance to the strategy and adapt. For this work, more extensive metric development through example is presented in the Methodology review, section 3.

1.3.4. Is the proposed Framework effective at identifying areas of opportunity and action across a resource management chain?

Philosophies only gain value when practically applied and proven. This research applies the ISDMF to electricity management in three communities identified by third parties as having highly, average, and un-sustainable resource use for a given technology and behavior option. Analysis is performed as an objective participant in the market, which could be represented as a legislator, community member, or resource provider. As described in the preceding development, while individual motivations may differ, a sustainable long-term resource outcome will be assumed as the desired goal by each represented group.

The method applied for case study analysis will be heuristic, meaning that existing publically available data will be compiled and analyzed under the Framework structure. Further, assessment assumptions will be made based on published or communicated industry practice and incorporated in analysis. These assumptions are defined in Method, section 3.

Resource Selection for Case Studies: Electricity

The ISDMF is designed to address any competitive resource, but for demonstrative application electricity is chosen for assessment. Selection of electricity as a core sustainability resource is driven by its importance for modern communities. Electricity is identified as a top factor affecting social prosperity. As noted by Smalley (2005), energy can overcome challenges posed by nearly all other constraints.

While critical to sustainability, this resource is somewhat atypical for resource assessment as it is a processed or secondary resource. Uniquely, as a commodity and not a 'Common', electricity is immediately exhaustible if not stored and can only be generated using either centralized or distributed competitive technologies. In addition, electricity availability and generation affects a wide range of

'Common' resources. It can be generated, imported, exported and consumed by individual players and as such cannot be considered a Common. Rather, it is a resource that indicates common resource use and sustainability management efforts with resolute impacts within communities. Electricity is also worthy of assessment as continued demand increases society continues to grow and adopt electricity enabled necessities and conveniences.

Electricity is a century old invention, and it governs society's ability to create other required resources ranging from air, water, food, and luxuries. As was described by Richard E. Smalley (1943-2005), Nobel Laureate in Chemistry (1996), in his 2004 article Future Global Energy Prosperity: The Terawatt Challenge, the perspective that (p. 413-414):

> "When we look at a prioritized list of the top 10 problems, with energy at the top, we can see how energy is the key to solving all of the rest of the problems—from water to population:
>
> 1. Energy
> 2. Water
> 3. Food
> 4. Environment
> 5. Poverty
> 6. Terrorism and war
> 7. Disease
> 8. Education
> 9. Democracy
> 10. Population"

As Dr. Smalley explains, energy can be viewed as the primary factor affecting and mitigating other resource pressures. This perspective is further reinforced by the United States Department of Energy (DOE) through their office of Energy Efficiency and Renewable Energy (EERE) website: "Most economists link electricity consumption directly with economic growth." (2011b) Because of energy and more specifically electricity's influence over other resources, growing demand and stressed supply, and substitution capacity for other energy types, this research will then operate the ISDMF within the context of a two player game between the Community and respective electricity Utility as unique game 'players' in the electricity space.

Technological Dislocation Driving Innovation: Distributed Residential Photovoltaic Generation

Historically electricity operates under a centralized generation scheme with a Utility offering generation, transmission, and distribution conduits. As the majority of Utilities are privately owned, cost recuperation and stable profit models govern their operations. This is largely due to efficiency in centralized generation dependent on large scale combustion, respective primary fuel delivery, consistency, and magnitude of required infrastructure.

However, modern developments toward economically viable alternatives today allow centralized electricity purchasers more distributed options for localized generation that compete with established, centralized Utility resource delivery. These emerging innovations stimulate societal decision-making, and instigate a platform to apply the developed ISDMF to evaluate the most sustainable migration from the 20th Century fossil and nuclear fuel driven centralized structure toward distributed, renewable electricity alternatives.

With identification of vision, goals, resource and base players definitions complete, analysis can begin moving through the remainder of the ISDMF process. As was developed in section 1.3.3.2, Establish Scope of Study, only a couple definitions remain to begin Framework application for a sustainability study of electricity: (1) Define System Boundary, (2) Define Players (in more detail), and (3) Characterize Metrics to Quantify Vision and Goal Progress. The following sections develop these points for case study and to assess Framework effectiveness as a primer for Method section 3.

Define System Boundary for Case Studies

Case studies will be geographically defined by city selection and service territory of the major electricity Utility within city limits. All other analysis parameters are set through this scoping activity. Case study cities are selected based on two iterations of nationwide energy sustainability reputation initially performed in April of 2012, and more recently a December 2012 assessment to confirm published ranges of sustainability success when considering incorporation of residential photovoltaic electricity generation. Three distinct cities with respective utility service areas are selected apply the

ISDMF and confirm usefulness via comparative assessment as will be presented in the Methods, Results, and Conclusion sections. The identified cities for case study are Portland, Oregon; Phoenix, Arizona; and El Paso, Texas..

Chronologically city sustainability rankings illustrate the dynamic nature of community action. The April, 2012 review of city energy sustainability comparisons showed a lasting history for Portland, Oregon as a top recognized sustainability city based on evaluations by SustainLane, a federally supported third party assessor (Environment News Service 2008, as an example). Introduced in 2005, SustainLane reports its City Rankings have been a catalyst for change, claiming that both the median and average scores have increased across all cities surveyed since 2005. The "Portland region has received several green rewards, usually ranking as #1 on any list of the most green US cities and in 2008. Popular Science Magazine even named Portland as the greenest city in the whole U.S.A." (Englebert 2012)

Unfortunately, Phoenix was not listed in the SustainLane rankings, but generally was viewed as a 'worst' performer. As an example "Bird on Fire: Lessons from the World's Least Sustainable City" by Andrew Ross describes how "Harvesting the sun for energy had a history in the region, but it was a troubled, if not entirely abortive, one." (Ross 2011, p.154) Ross discussed how utility influence can greatly limit proliferation of distributed solar generation, and how their "cutoffs [to distributed solar generation] were a stark reminder of how tightly these [electricity utility] monopolies controlled the alternatives to their core business." (p. 174)

Finally, El Paso, TX was added as a third case study city to fall between the high and low sustainability reputations of Portland and Phoenix to test the ISDMF. In the April sample targeting assessment, El Paso was not found in national rankings but was referred to as the 'Sun City' based on relatively high solar insulation and municipal action. In addition, El Paso is the University of Texas at El Paso city of residence and presents value for comparison between the two extremes of Portland and Phoenix. El Paso is also the locale where the author can directly engage as a community member and observe sustainability development. Beyond these more immediate consideration factors, El Paso

reputation was further researched and found to suggest middle placement by Smarter Cities, a project of the Natural Resources Defense Council (Smarter Cities 2010).

Since that initial study of target Framework application cities in April of 2012, policy and energy actions in those communities highlight the dynamic nature of sustainability efforts and results. Several more recent studies were released to understand sustainability rankings, but challenges remain as no comprehensive and active system is available to evaluate energy sustainability reputation rankings over significant time frames. But many organizations pursue and publish sustainability ranking information, and as another example Siemens, supported by the Economic Intelligence Unit (2011), maintains the internet based Siemens evaluation tool (2012) which provides some additional insight, albeit limited. Phoenix is the only city originally selected that appears on the list; the Siemens study shows that Portland appears to begin slipping in 2009 and El Paso is not mentioned.

The most comprehensive study found in the public domain to include all three cities is a report issued by the Corporate Knights and Dr. Kent Portney, a Tufts University Professor. He works as a sustainability consultant and renowned author of 'Taking Sustainable Cities Seriously'. The Portney study provides a comprehensive sustainability ranking for each of the three cities identified for ISDMF testing in a single listing. In Portney's work, Portland again resides at the top position tied with Seattle and San Francisco. Phoenix ascends to number eight in the country, and El Paso ranks in 33rd position (Portney 2013). Again, Dr. Portney's work is the only identified study of sustainability reputation found to include all three test case cities, and demonstrates the dynamic nature of sustainability planning, action, and outcomes based on observed history. This Green Cities study conducted and maintained by Dr. Portney will be used as the final support to validate the selection of these three case study cities based on reputation.

Additional studies are available to qualify test cases based strictly on photovoltaic installations. The California Solar Energy Industries Association (CALSEIA) recently released a new report titled “Shining Cities: At the Forefront of America’s Solar Energy Revolution.” This report contains a quantified assessment of solar activity by major U.S. city. The city summary table is included below, and of the top 20 cities ranked, Phoenix holds third position with 96 MW capacity and Portland ranks

15th with 15 MW. El Paso is not listed. Also, these rankings include Utility scale data beyond specific residential PV.

Table 1.3.4.1: Top 20 Solar Cities by Total Installed Solar PV Capacity, End of 2013 (CALSEIA 2014)

Principal City	State	Cumulative Solar PV Capacity (MW)	Cumulative Solar PV Capacity Rank
Los Angeles	CA	132	1
San Diego	CA	107	2
Phoenix	AZ	96	3
San Jose	CA	94	4
Honolulu	HI	91	5
San Antonio	TX	84	6
Indianapolis	IN	56	7
New York	NY	33	8
San Francisco	CA	26	9
Denver	CO	25	10
New Orleans	LA	22	11
Sacramento	CA	16	12
Jacksonville	FL	16	13
Albuquerque	NM	16	14
Portland	OR	15	15
Austin	TX	13	16
Las Vegas	NV	13	17
Newark	NJ	13	18
Raleigh	NC	12	19
Boston	MA	12	20

Utility territory is the other boundary needed to define test cases, and for this study the Utilities selected will be Arizona Public Service for Phoenix, El Paso Electric for El Paso, and Portland General Electric for Portland. The El Paso case is a unique case where a single utility services the entire municipality. In the other two cases, utility service territory is a subset of the city area and is defined by the city area codes serviced by the selected utility.

Player Definition

Community migration away from electricity produced by a centralized utility is currently limited, but is anticipated to accelerate with continuous efficiency improvements and decreasing cost of technology and installation. (EIA 2013a) Accordingly, communities and current service providers are expected to engage in increased competition. To better understand the current state of electricity delivery, analysis can be made under the ISDMF to understand factors affecting interplay and obstacles between Utility and Community players. Within the Framework, two players exist for each case study under the Framework structure.

For the Framework application, the definitions of electricity players are (1) the incumbent provider offering electricity under a Centralized model as the "Utility", and (2) the current residential consumer with the option to incorporate distributed residential photovoltaic technology into electricity generation profiles termed the "Community". Each of these two players have unique motivations which can create conflict and inherent economic / environmental considerations generally regulated by policy and government oversight.

As was mentioned traditional, centralized electricity generation and delivery has been in use for over a century. The justification has been cost because large power plants with transmission and distribution infrastructure historically are more efficient and reliable when compared to Community owners that operate smaller, property specific generation. However, advancements in scalable, renewable technologies can now empower citizens to potentially improve cost and delivery options that may offer additional environmental and social benefits. The ISDMF will be applied to develop a sustainability strategy for centralized versus residential photovoltaic distributed electricity based on the following two player sets.

Player 1: Utility as a Centralized Resource Provider

Utilities are the first player for this test application of the ISDMF, and are characterized as centralized electricity generators and delivery providers for this study. Centralized electricity utilities

require large investment in physical infrastructure, with unique electricity lines installed for each Community customer. This physical construct establishes the Utility as a ‘natural’ monopoly which benefits from large geographic ranges to earn operational profit. Utility investments in generation, transmission, and distribution infrastructure cost into the billions, and it can take decades to achieve payback for initial investment. Because of high startup and operational costs, utilities naturally discourage smaller player competition as they strive to maintain high revenue and sufficient hurdle rates. In addition, Utilities are also often motivated to vertically integrate production and delivery of primary fuel sources for uninterrupted generation. Expansive investment is pursued by the Utility to achieve efficient and continuous electricity delivery at a desired profit (Arocena 2012).

Utilities are generally adverse to support community based distributed generation as these actions erode revenue and are viewed as providing sporadic capacity. However, many utilities now recognize that some level of distributed generation (DG) may offer benefits to enhance their businesses, and do engage with DG expansion to varying degrees. While migration of customers to residential distributed generation may represent revenue erosion, Utilities could feasibly increase profit margin at decreased revenue due to multiple factors that can augment profit to include:

- Grid Efficiency – While energy security and carbon footprint concerns offer financial benefit in various scenarios, immediate utility opportunity for residential photovoltaic system deployment resides in localization of generation at the demand. Advances in technology indicate that traditional models of large scale generation with vast delivery grids is in debate, and could be augmented by solutions more localized to the end user. This strategy can combat high startup and operational costs, better leverage regional comparative advantages, decrease pollution, lower grid inefficiencies, and reduce risks of outage, infrastructure repair and maintenance. With those considerations, challenges to the current Grid transmission and distribution infrastructure exist, and could be mitigated by incorporating residential photovoltaic systems. Some statistics to support these theories include:

- Antiquated infrastructure poses risk from outage, even at a system uptime of 99.97% (U.S. DOE 2009a). It is estimated that power outages and power quality disturbances cost the U.S. economy from $25 to $180 billion annually (DOE, Office of Electric Distribution and Transmission 2011), with the majority of these costs being absorbed by the utilities in contract disputes. These costs could soar if outages or disturbances become more frequent or longer in duration. As an example, during an interview on November 17, 2012 with David Carpenter, Senior Vice President - Chief Financial Officer of El Paso Electric, he described how over 60 transformers were blown around the city of El Paso causing outage. DG offers an opportunity for utilities to address near term demand challenges and infrastructure stress by offsetting peak demands.
- The 2010 U.S. Energy Information Administration (EIA) State Electricity Profiles (2010a) indicate that the current national grid has an efficiency loss of approximately 9.4%, which has been growing over the past decade (defined as Net Generation/Total Retail Sales). In the early 1990's, grid loss was estimated at between 6-7 percent. The inefficiency growth is attributed to heavier utilization and more frequent congestion. DG alleviates this problem by installing generation closer to demand and decreasing delivery congestion.

- Large, centralized plant startup and shutdown costs can be high and unprofitable, requiring profit consuming coordination at the Utility. These costs result in higher delivery costs, even exceeding retail rates. Sale at a unit loss decreases Utility return on investment (ROI). DG reduces peak demand under largely centralized generation scenarios, and allows for higher equipment utilization factors through better demand leveling.
- Energy Security – Implementation of widespread, residential photovoltaic systems pulls energy production to demand sites, thereby eliminating dependency on resources not

'immediately' accessible due to systemic outages. This backstop can help the Utility when exposed to the spot market for peak demand by reducing peak system consumption.

- Electricity availability is threatened by increasing demand and constrained supply. From the US Department of Energy (DOE) Energy Efficiency and Renewable Energy website, “Analysts at the U.S. Department of Energy (DOE) Energy Information Administration (EIA) project that the U.S. gross domestic product will grow at an average annual rate of 2.9% per year through 2030. In addition, they predict electricity consumption will grow over this same period at a rate of 0.8% per year. That means electric power consumption, and the accompanying infrastructure to produce and deliver electricity, will be about 43% greater in 2030 than it is today.” (2011)

For these reasons and on a limited basis, Utilities engage renewable energy generators (typically solar and wind) as subcontracted providers to meet Renewable Portfolio Standards. They also participate in subsidy programs to promote residential adoption.

The Energy Information Administration arm of the Department of Energy separates electricity providers as a community service provider into five categories and tabulates energy generation and sales data for each type of plant ownership. Their most recent data published on November 3rd, 2011 for 2010 showed a US market size of 3.37 billion megawatt hours and a value of $326 billion USD divided across the following distribution of organization types: Investor Owned (67%), Public (15%), Cooperative (13%), Power Marketer (5%), and Federal (0.03%). (EIA 2011b). Note that the three Utilities included for Framework application as case studies are all investor owned entities (Portland General Electric (PGE), Arizona Public Service (APS), and El Paso Electric (EPE)) which makes comparison of ISDMF results for each test case more accurate.

Player 2: Community as a Distributed Resource Provider

The second player in these case studies is defined as the residential centralized generation customers (utility customers) able to adopt residential grid-tied photovoltaic systems, and are termed the

"Community" in this work. Communities face challenges regarding electricity sustainability principally surrounding cost and environmental impact. Contractually, Utilities are obligated to deliver electricity under specified agreements and pricing schedules. Centralized electricity delivery in the United States is relatively dependable at the previously stated 99.97% up time availability at Utility Commission approved rates. With these government protections and ready availability, Communities find comfort with Utility structure and preserve the current centralized electricity approach. However, the Community can now, with technology innovation, proactively consider if centralized distribution models are the most sustainable approach, or if migration to distributed generation could gain enhanced financial returns and realize supplementary benefits in job creation, environmental protection, and goodwill over the status quo. Communities focused on sustainability must assess risk and return, auxiliary factors, centralized or distributed structures, and how their decisions impact long-term electricity sustainability.

Strategically, test case Communities will be evaluated using the ISDMF to make adoption decisions regarding residential photovoltaic systems as a potential solution to alleviate several concerns affecting Quality of Life. Some of the strategic considerations important to the Community are:

- Residential Electricity Cost - Many financial models demonstrate, assuming expected equipment reliability, that DG investors achieve competitive rates of return over the Utility by purchasing a residential PV system based on initial system purchase price, grid connection policies, and expected avoided centralized electricity cost.
- Environmental Impact – Harnessing the sun's power is a virtually carbon free solution to meet electricity demands. Outside of the manufacture of systems, no additional fuels are needed to operate a PV system, which in turn promotes a cleaner environment, conserves water, and can reduce aesthetically intrusive infrastructure in the Community.
- Workforce Creation and Local Preservation of Capital - Community employment is boosted through installation and ongoing support of DG, coined 'Green Jobs' in the industry. Financial assessment of residential photovoltaic installation suggests that over

30% of a system purchase price remains in the Community (Based on confidential interviews with El Paso Installers in 2013).

- Expanding Communities face higher electricity rates due to increasing Utility operational costs, rate negotiation, and coordination of infrastructure expansion. The U.S. DOE estimates that in 2010 interlinked, centralized electricity systems include over 3,200 utilities, over 10,000 generating units, tens of thousands of miles of transmission and distribution lines, and millions of customers (EIA 2011b). Infrastructure impacts allow two key business opportunities for Community based DG to meet growing community electricity demands for rapid deployment:
    - Grid spurs to integrate renewable energy efforts can be difficult to permit and construct due to contract negotiation and environmental impact pressures. A renewable installation typically takes 1 year to develop, but grid integration can last delay startup for many more years with easement acquisition and transmission construction and upgrade, which indicates a need to engage project management on the grid development or permit activities. Acceleration of capacity through with DG adoption ensures faster convergence to potential sustainable energy solutions.
    - Grid transmission performance may benefit from Community migration from traditional, centralized delivery management by reducing line losses as benefit of this DG technology.

Metrics to Assess Sustainability

The defined players, system boundaries, and resource establish the Current State basis to study electricity sustainability focused on centralized generation models versus a more distributed generation approach. To complete the initial Current State assessment, these parameters are incubated to establish an initial set of metrics to monitor resource strategy performance and establish goals. The ISDMF

outlines two metric points of initiation prior to engaging action: (1) Metric determination during the Current State assessment process step, and (2) metric enhancement once all other Framework assessment steps are completed.

The first metric assessment is a brainstorming activity to capture any factors to control and improve through sustainability action. This initial metric set is divided into four principle segments based on the Framework structure: (1) Individual Community member financial motivation and current state adoption level and rates, (2) cooperative system impacts by assessing peak generation, potential PV peak generation market size, and PV generation potential, (3) Utility affects of full scale implementation in terms of revenue decrease, potential margin contribution, and mitigated infrastructure development and maintenance costs, and (4) auxiliary Community impacts of softer' costs and benefits to include air quality, projected water consumption offset, community capital preservation from local investment, job creation, and educational impacts to the community in becoming more 'green'. A complete list of Current State determined metrics for this assessment is provided in Appendix C.

Current State metric determination provides a directional basis to identify measurement points and available data across the remaining Framework process steps. The measurement ideas posed above were reorganized into categories more aligned with the Framework sequence. Final metrics were again grouped into four distinct categories, but different and more comprehensive than the original Current State form. Most principally, the sustainability adoption levels are based on estimated and optimized Utility financial benefit. This is achieved by focusing on unit marginal cost to the Utility at zero, and calculating PV adoption levels to replace unprofitable unit sales. With this key assumption, final categories for test case application include (1) individual Community investor motivation, (2) individual Utility motivation, (3) cooperative impacts, and finally (4) Adoption levels and rates to define current Community and Utility position. These detailed metrics are presented in summary tables 3.8.1 and 3.8.2 at the end of the Methods section. All assumptions and details used to develop the metrics are reviewed throughout Method, section 3.

1.3.5. How can the availability of a new, proven framework contribute to effective and efficient sustainable decision-making?

Resource sustainability strategy design and execution are essential for continued societal advancement. Future continued or improved prosperity depends on intelligent resource management, and errors in sustainability assessments and deficient execution can result in increasing cost, decreasing resource availability, and threatened Quality of Life.

Today, the total human biomass is already as much as a hundred times the biomass of any large land animal species that has ever lived (Wilson 2002), and because of this dominate the environment and dramatically affect it. The ISDMF provides a novel sustainable strategy check list for players to more efficiently and effectively converge on structured application of resource sustainability philosophies and tools to enable improving Quality of Life for today and in the future. The Methods, Results, and Conclusions sections address this research question by comparing each test case under a standardized metric set to determine best practices and opportunities for improvement.

1.4. Project Summary

Research Development History

This work is the result of a long incubation process where each successive scope iteration has grown the sustainability relevance of the ISDMF. Initially, during the month of April, 2011, the first project proposal focused on the impact of subsidy as a vehicle to promote adoption of residential photovoltaic systems in El Paso. After consideration Dr. Barry Benedict, Committee Chair, determined that initial subject matter to be too narrow to provide scientifically significant value. From that basis, the work broadened scope to also incorporate Diffusion of Innovation concepts beyond subsidy factors applied within El Paso.

This next scope iteration was determined more strategically valuable, but after review was also considered too narrow to advance the science of sustainability. During early Spring semester, 2012, geographic range was then added as a means to expand the study, to include cities that would provide

diverse representation of environments for high, middle, and low adoption rates as an indicator of electricity sustainability decision-making. This addition expanded the work to a national relevance, but the project remained limited for potential to achieve widespread influence. Because of this, project scope was again expanded to synthesize prior investigation efforts into a comprehensive sustainability 'Framework', which would be independent of any particular resource, scenario, or location. The defined economic, diffusion, and testing concepts were then reassessed to encompass an expanded theoretical view. As the final iteration of scope, Archetype theory was added to create a more comprehensive approach to include risk assessment and suggested corrective actions. These further realizations and enhancements are paramount to arrive at the work presented here, and development of this approach began at the beginning of the Summer semester, 2012.

This new project concept was vetted in a high level presentation with the Committee members, Dr. Chianelli and Dr. Krause, prior to full scale launch of dissertation development in middle July. Content development continued through the Fall, 2012 semester and additional Committee members were considered beginning 2013. An invitation was extended to Dr. Arvind Singhal during the Fall semester, 2013 when he joined the Committee.

Research Construct and Development

The resultant ISDMF transcends local application to become a work product with broader application than the original proposal. Theoretical components require documentation to support development of the ISDMF, and research indicates that the currently available sustainability frameworks are limited based on key factors of sustainability science approachability and widespread use.

Creation of a general framework for sustainable decision-making requires comprehensive assessment and description of contributory theories which can be summarized into three key research elements: (1) Assess existing frameworks based on integrated, approachable, and actionable intent for sustainable decision making to verify this proposed Framework expands sustainability science, (2) if existing frameworks that meet community need cannot be identified, identify and integrate sustainability governing theories that establish the desired Framework and address gaps observed in current

framework offerings, and (3) present the resultant ISDMF and assess viability by applying it to real world application through case studies.

With this project plan in place, the first step was to identify the spectrum of available frameworks and an objective means of evaluating their approachability to a wide set of resource chain participants. Sustainability frameworks were discovered which necessitated a method to categorize and evaluate approaches based on merit and deficiencies. Each framework category was then evaluated based on approachability and usefulness to guide a general user to specific actions toward sustainable solutions. Finally, each framework category was evaluated based on its level of use. These activities were completed and the summarized research is provided in the Literature Review section.

The review of prior works and subsequent analysis demonstrates a need for the ISDMF as a sustainability strategy development tool. Current toolsets appear limited by the lack of a framework that reaches beyond specific groups. As a result, the development of a novel sustainability Framework is presented herein. Descriptions explaining each process step and factor of the ISDMF are included in brief as an Introduction of this research, and additional explanation of the ISDMF design is available in the Literature Review section.

The ISDMF viability assessment will be conducted throughout the Method and Results sections. The Methods section develops the application of the ISDMF for electricity and related sustainability metrics as discussed in brief above and expanded in the Methods section. These assessments compare centralized, incumbent generation, transmission and distribution blended versus residential distributed grid-tied photovoltaic generation of electricity. The developed metrics establish an objective set of criteria to apply across three different case studies of selected communities. City boundaries and utility service territories geographically define communities, and they will be chosen based on their published reputation as current sustainable electricity consumers. To reiterate, the proposed cities are (1) Portland as a high sustainability rated community, (2) Phoenix as it is generally seen as a low or poor sustainability manager of electricity, and finally (3) El Paso as a relatively 'middle of the road' sustainability participant and the community where research is principally conducted. The concept behind consideration of three different cities is to assess Framework effectiveness to identify best

practices and deficiencies in sustainable management of the selected resource, profile current adoption levels and rates, and analyze potential for residential PV adoption if determined to be a worthwhile sustainable action. A summary of individual and comparative assessments for each city applying the ISDMF will be included in the Method and Results sections.

The following process flow illustrates the general Framework application for the described case studies defined throughout the preceding sections as figure 1.4.1:

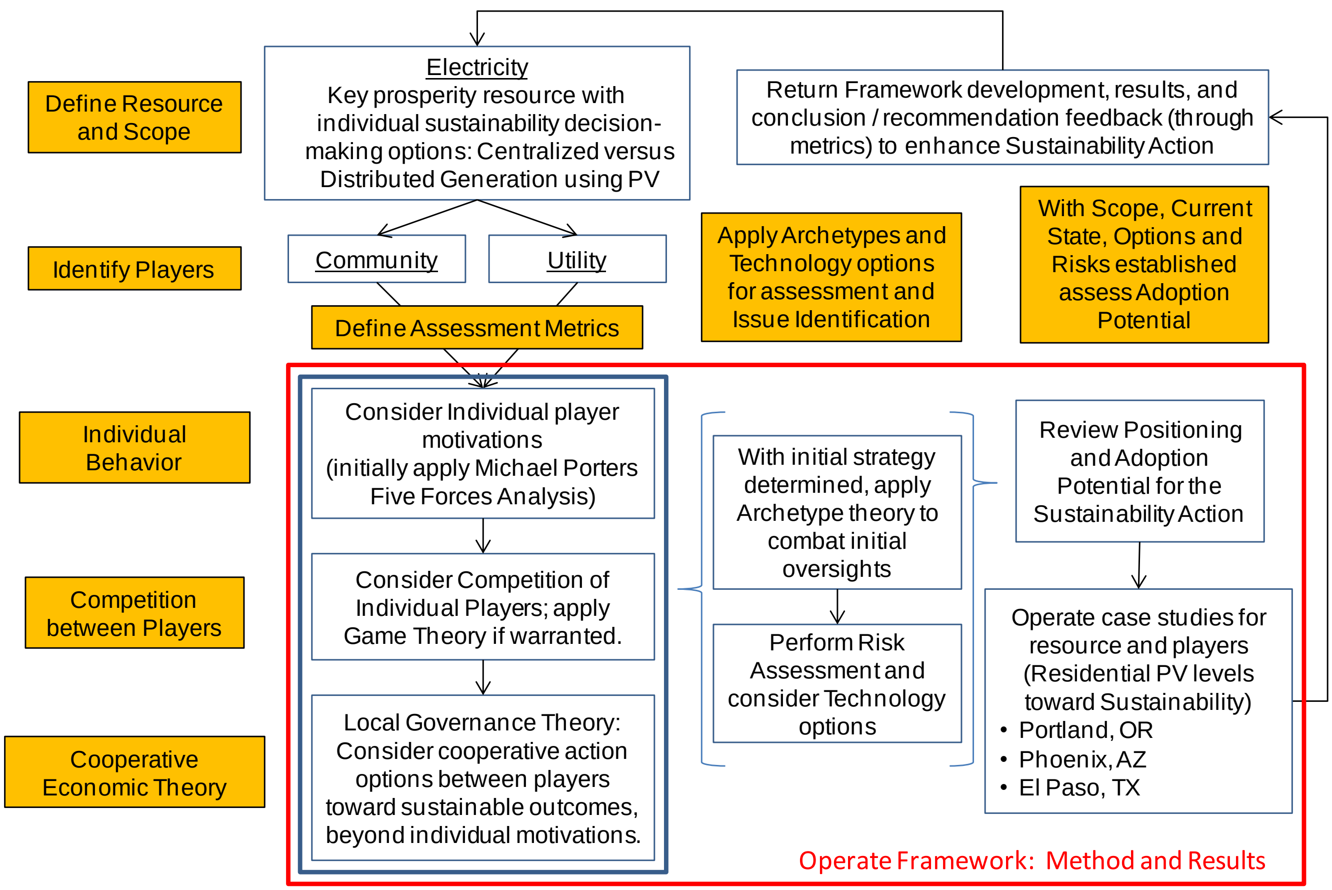

Figure 1.4.1: Framework Research Process Overview

Data sources for this study will be International, Federal, State, and Local assessments available in the public domain, which is characteristic of heuristic study. In addition, any identification of a data

gap is a valuable observation indicating a potential deficiency in Framework application. Finally, with the Method and Results developed, Conclusions and Recommendations are made regarding Framework uniqueness, utility, and case study observations from practical application. Each city's electricity sustainability position, determined factors affecting strategy action, and answers to the Research Questions will be provided.

1.5. Researcher's Personal Connection and Motivation

My life has changed dramatically over the past 8 years. I purchased a home, started a family, and began contemplating my career as a community contributor. I have always strived to keep a watchful eye on conservation and efficiency from years in business process development, but recently recognized that my professional pursuits could offer more than increased returns for corporations. I found myself reading and viewing programs to learn more about anthropogenic impacts on the environment, and was particularly drawn to energy issues. Over time, I have become an active citizen concerned about energy sustainability in the United States and Worldwide. In response to this realization, I started changing several elements of my life as demonstrated through my classes and research efforts at UTEP, community work, investments, and career aspirations that solidify my commitment and interest toward resource sustainability practice.

I live in El Paso and witness adverse air quality effects of city growth, job erosion and outsourcing to lower cost regions, outflow of capital and market instabilities, drought, and higher temperatures to name just a few observations and concerns. These realizations are startling, and I came to believe that I had to take action not only to change my own behaviors but also to set an example for my young children. I started applying my growing knowledge of sustainability theory across all levels of resource use under my control. As a few examples, my water bills have been nearly reduced by half while maintaining a more sustainable garden using drought resistant plants and mulching. I am proud to say that I made the sustainable choice and migrated to renewable, distributed electricity after working to reduce consumption, and use networking tools to greatly limit the use of my vehicle which cuts my emissions footprint from driving. We, as a family, have made the decision to purchase 'good used' instead of buying new when possible.

This research topic was spurred by the realization that I can personally continue to improve, and I began to recognize that large segments of our community seem to overlook clear sustainability options that offer both individual and collective benefits. After dabbling with sustainable policy development in the UTEP program, I began reaching out to the City of El Paso, local distributed energy installers, the local water and electricity utilities, and actively participate in advocacy groups to understand the industries and community efforts in play. I was surprised to learn how curious and interested the El Paso community is in sustainable resource management, but that tractionable results may remain limited. I demonstrated to myself through action that sustainable decision-making provides immediate returns, and that education and awareness are the core enablers. Further, once success is realized and a participant enjoys immediate financial benefits as well as the personal satisfaction gained through sustainability decision-making, they are likely to incorporate the sustainability process in their behaviors. For example, since acquiring a residential PV system for my home, I actively monitor my generation versus consumption and have identified other energy saving opportunities.

For these reasons, I have chosen to pursue a research focused on creating the ISDMF and hope to socialize the result to the broader community for action. This effort leverages my over 20 years of engineering, international business, and academic experiences with current focus and interest, and proves quite challenging. I consider myself an early adopter, and my decisions to date have proven great investments not only from an economic perspective, but also for the personal satisfaction derived from making better environmental decisions. As has been mentioned throughout this text, the intention of my dissertation is to create a decision-making framework that is (1) approachable so that all understand it, (2) actionable to actually influence change, and (3) adoptable to gain acceptance and use. Through this dissertation process, I also hope to answer my own questions regarding the level of risk versus return the public will accept to accelerate adoption of solutions. Much of this argument has historically been subject to speculation, and this study hopes to better develop these market factors into a Framework and dataset that promotes initial local efforts and more widespread resource sustainability in the future.

Literature Review

The Introduction provides a high-level overview of the ISDMF, currently available framework types and differentiators, and test case method to prove Framework utility. In this Literature Review section, Framework development expands to present uniqueness by reviewing the population of identified framework categories and examples, ISDMF differentiation, and concludes by providing more detailed descriptions of the prior contributory theories that enable the Framework.

Prior work plays a large role to understand differentiation of the ISDMF as an actionable, approachable, adoptable framework beyond existing, identified frameworks. Throughout this Literature Review, the major objectives are to understand past framework development efforts, define a status quo of publication and use, and recognize opportunities for improvement in the current offerings. From there, this review supports the ISDMF as presented in the Introduction by specifying and expanding on contributory theories to support practical use.

2.1. Existing Sustainability Frameworks – Categorization and Examples

As mentioned in the Introduction, Todorov, V.I. and D. Marinova made a broad attempt to classify the range of models or 'frameworks' in use in their 2009 paper Models of Sustainability. They postulate that four basic types of sustainability strategy development and communication tools exist: (1) Pictorial Visualization, (2) Quantitative, (3) Physical, and (4) Conceptual approaches. (Todorov 2009) The following excerpts from their publication provide detail on definitions, and published examples of frameworks and models currently in use are provided as support of their findings.

The science of sustainability is an "extremely complex concept and a new way of thinking," (Todorov 2009) and a wide range of approaches exist. Todorov's work explains that "existing models represent the historical conceptualization of sustainability starting from environmental constraints and moving towards economic valuation and social behavior and policies. However as any model is a simplification of the complex reality, the main purpose of any sustainability modeling should be to allow for co-evolution to be represented, including the role of humans as sustainability guardians." (Todorov 2009, p. 1216)

Pictorial Visualization Types

Perhaps the most basic and widely reproduced means of presenting 'sustainability' and its base factors is through a pictorial representation. This is often portrayed as a Venn diagram that indicates the interplay of Social, Environmental, and Economic considerations. The Triple Bottom Line or TBL, a popular version of this framework type, was published by the World Conservation Union (WCU) in 2006 and reproduced from Todorov's work below:

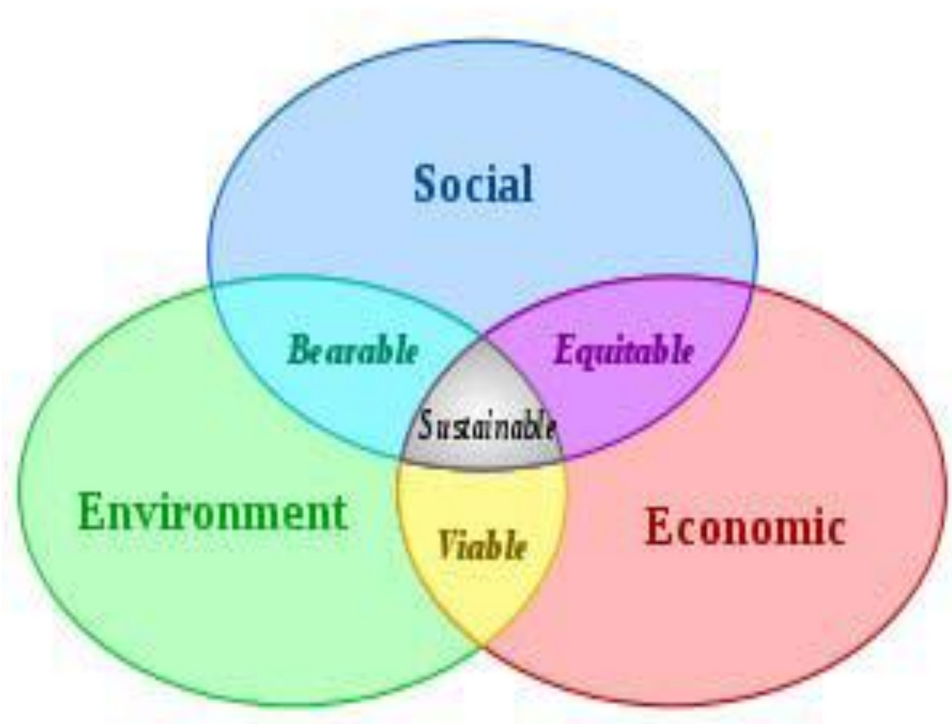

Figure 2.1.1: Example of the Triple Bottom Line (TBL) Venn diagram (Todorov 2009)

This high level, visual representation illustrates the need for 'interdisciplinary and transdiciplinary' approaches to understanding sustainability (Marinova and McGrath 2005). In this pictorial example of the TBL, simplicity and comprehensiveness promote approachability and adoption but the lack of more specific theory content limits use to define sustainability strategy for action. Aside

from this shortcoming, the TBL is a useful framework to communicate sustainability to a wide and diverse audience. In fact, it is so popular that elements of the TBL appear in the majority of other frameworks identified. A case in point is the following pictorial representation of the Triple Bottom Line (TBL) blended with the Brudtland results, with the addition of market forces indicated by the researcher to help develop the ISDMF.

The Triple Bottom Line of Sustainability and Macro-Economics

The TBL concept presented in the preceding sub-section is very useful to organize high-level sustainability initiatives in concept, and is often used as a basis for more detailed approaches. In the development of the TBL with macroeconomics and Brundtland findings combined, several additional drivers influence sustainable resource solutions. From the base TBL representation, the following framework applies a relative metric on each of the three main TBL categories (Social Justice, Environment, and Economics), and incorporates a reference to the relationship of technology and consumer need. With the addition of a metric to rank a sustainability position to the TBL, each decision point in a sustainability trajectory is governed by these three factors, as illustrated in figure 2.1.2:

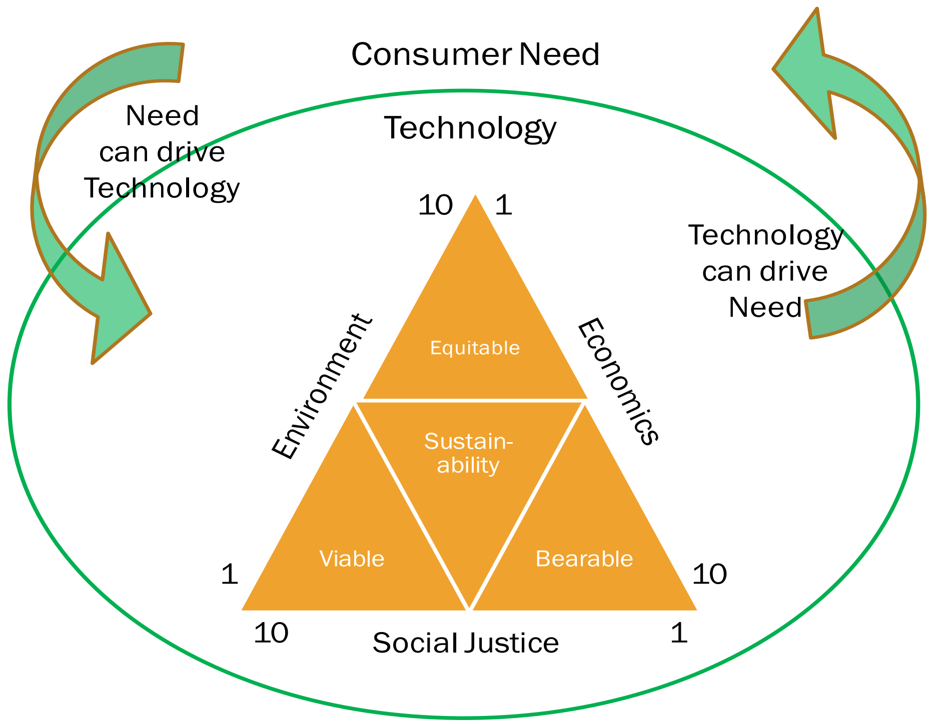

Figure 2.1.2: Market Dynamics with the Triple Bottom Line Concept

The intersection points of recognized need with technology present a region to apply the original TBL with metrics for continuous assessment. These assessment points are not merely fixed points, but more represent vectors of sustainability trajectory assessed at a specific point in time. Technology, as reflected in the diagram, continuously affects perceived societal need while simultaneously reacting to it. Effective communication facilitates commercialization, and technological learning curves can be accelerated by profit.

Policy establishment is also a major contributor as a vehicle to more rapidly migrate to a desired ideal state. Most critically in policy, diligent consideration of the relationship of the imagined ideal case or ‘need’ in society, the technological migration path, and how investment in an appropriate strategy can promote migration must be considered before issuance.

Two very similar approaches to the TBL with macroeconomics framework were proposed and applied by the Sustainable Europe Research Institute (SERI). These findings are published under the Methods and Tools for Integrated Sustainability Assessment project (MATISSE), which is a consortium of European sustainability experts led by the Dutch Research Institute for Transitions (DRIFT) at Erasmus University Rotterdam. MATISSE represents collaboration from its inception starting in 2001 to final publications in 2008, comprised of 22 partner entities with a goal "to achieve a step-wise advance in the science and application of Integrated Sustainability Assessment (ISA) of EU policies." (SERI 2008) Their models represent a multidisciplinary effort to develop what they term the Integrated Sustainability Assessment (ISA) frameworks to assess sustainability and develop implementation strategies. They define the ISA model as "a cyclical, participatory process of scoping, envisioning, experimenting, and learning through which a shared interpretation of sustainability for a specific context is developed and applied in an integrated manner, in order to explore solutions to persistent problems of unsustainable development." (SERI 2008a) In this third TBL based example, the pictorial Triple Bottom Line base has the addition of "boxes" to represent specific factors at each of the three category points. Categories (Environment, Social, and Economic) are implied in the center triangle, with domain factors shown as gray boxes connected with bi-directional arrows to imply two-way interactions.

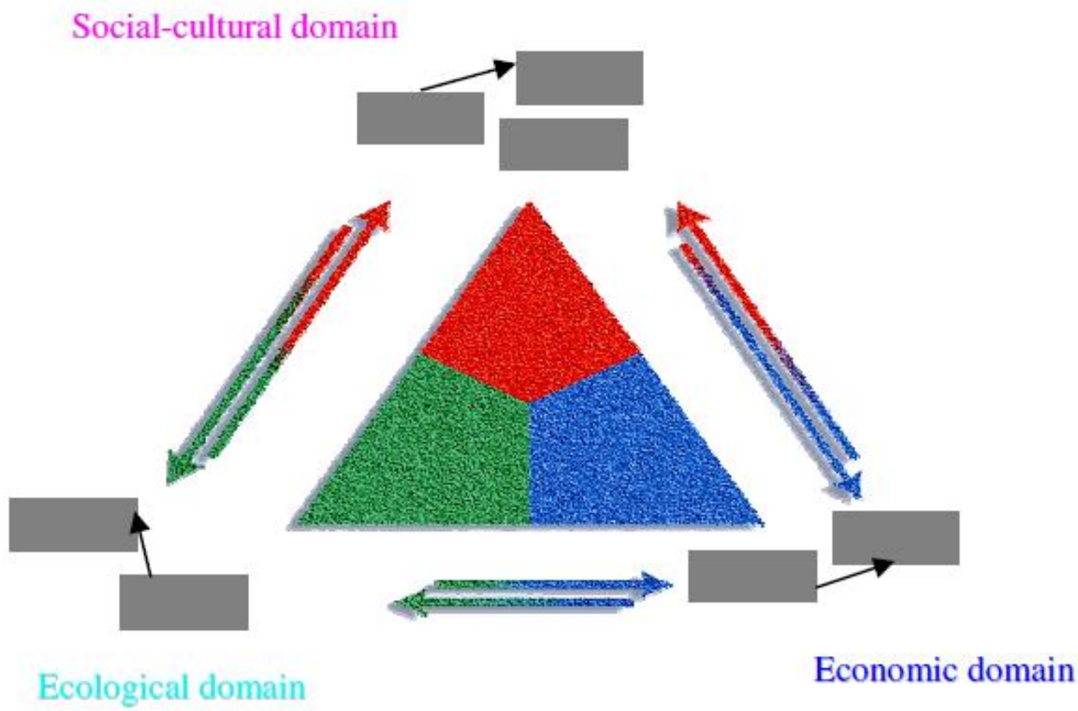

Figure 2.1.3: MATISSE Sustainability Thinking Framework - A Representation of the Triple Bottom Line Pictorial Model (Weaver and Rotmans 2006, p.8)

This baseline pictorial framework from MATISSE, however, does not clearly demonstrate the importance of the cyclical and ongoing nature of sustainability, particularly for their ISA concept. In response to this limitation, MATISSE members created another pictorial version with an implied Triple Bottom Line framework in its center. This next example specifies an outer ring of sustainability process steps required for the cyclical, continuous process of sustainable action. Their proposal is reproduced below as a fourth extension of the pictorial TBL concept:

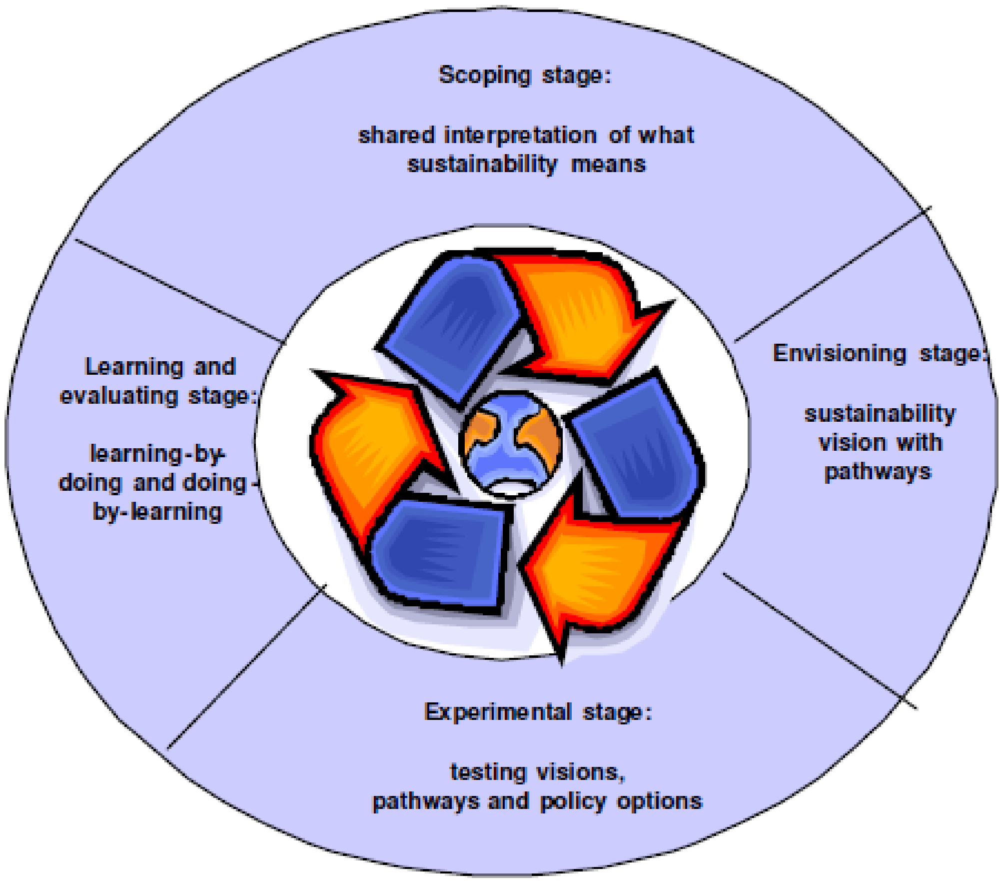

Figure 2.1.4: ISA as a Cyclical Process (Weaver and Rotmans 2006, p. 12)

While only examples of pictorial elements from the WCU, United Nations, the researcher, and MATISSE studies are reproduced here, many other examples exist with similar format. As can be observed, these pictorial examples are useful by being approachable and adoptable, but they are not well suited to define action. However, other existing frameworks are better aligned to identify specific action, with Quantitative frameworks the next type to review.

Quantitative Types

This second grouping labeled Quantitative frameworks encompasses data driven attempts to focus on a particular resource or group of resources, and apply quantitative methods to establish history,

current state and projected future outcomes. As with any type of numerical assessment and forecasting, these types of models are restricted by scope, assumptions, and data integrity.

While application of this type provides a more detailed structuring for sustainable strategy and action, Quantitative approaches face an inherent pitfall in that they often remain dominated by the discipline from where they originated, be it environmental science, engineering, or economics. (Rotmans 2006) In that sense, quantitative assessments traditionally are "poorly equipped to accommodate a holistic perspective, address the local-global perspective or acknowledge the need for stakeholders' participation." (Todorov 2009, p. 1218) However, this type of approach is very powerful when combined with more philosophical elements to identify specific projects to achieve sustainability vision and goals. As Todorov states, in this category are economic components that "represent a special sub-class of the quantitative models. In fact, this area has been extremely active in academic pursuit generating models representing various economic concepts, ranging from neo-classical, evolutionary, ecological economics to neo-Ricardian (Faucheux et al. 1996). These models have attempted to find ways of embracing uncertainty and dealing to a various degree of success with long-range perspectives." (Todorov 2009, p. 1218)

Below is an example largely driven by quantitative intention, which appears very complete and requires specific data based inputs across the 25 factors reflected. As a framework, it can prompt the user to consider many wide-ranging interactions of the unique factors as well as factor combinations. However, it does not expand on the concepts of rivalry, issue assessments and suggested solutions (archetypes), or proper diffusion techniques to drive community adoption. Rather, it is designed to focus on a particular company and unique project considerations to be made internally without competitive assessment.

Even with this extensive development, the framework is a 'stove pipe' approach with distinct limitations inherent to quantitative models. Nelms et al. describe the concept in the following context: The framework "was designed to accommodate diverse stakeholder performance criteria and be applied to all building types and technologies. The principles and structure of the framework are first introduced followed by a description of the six-phase framework process and the results of interviews with industry

professionals to illustrate their value systems and thought processes in the context of the green roof technology." (2007, p. 240)

Nelms declares that "four guiding principles of this framework are as follows: (1) building system or component is not an isolated entity but a part of, and it has implications for, other systems within the building as a whole; (2) framework must reflect the diverse set of values held by project stakeholders; (3) majority of project costs occur after the construction and during the operation and maintenance of the building; hence, performance over the total life cycle of the project must be considered; and (4) all new and established technologies are subject to risks and uncertainties that must be considered explicitly relative to project objectives and individual stakeholder perspectives." (Nelms et. al. 2007, p. 239)

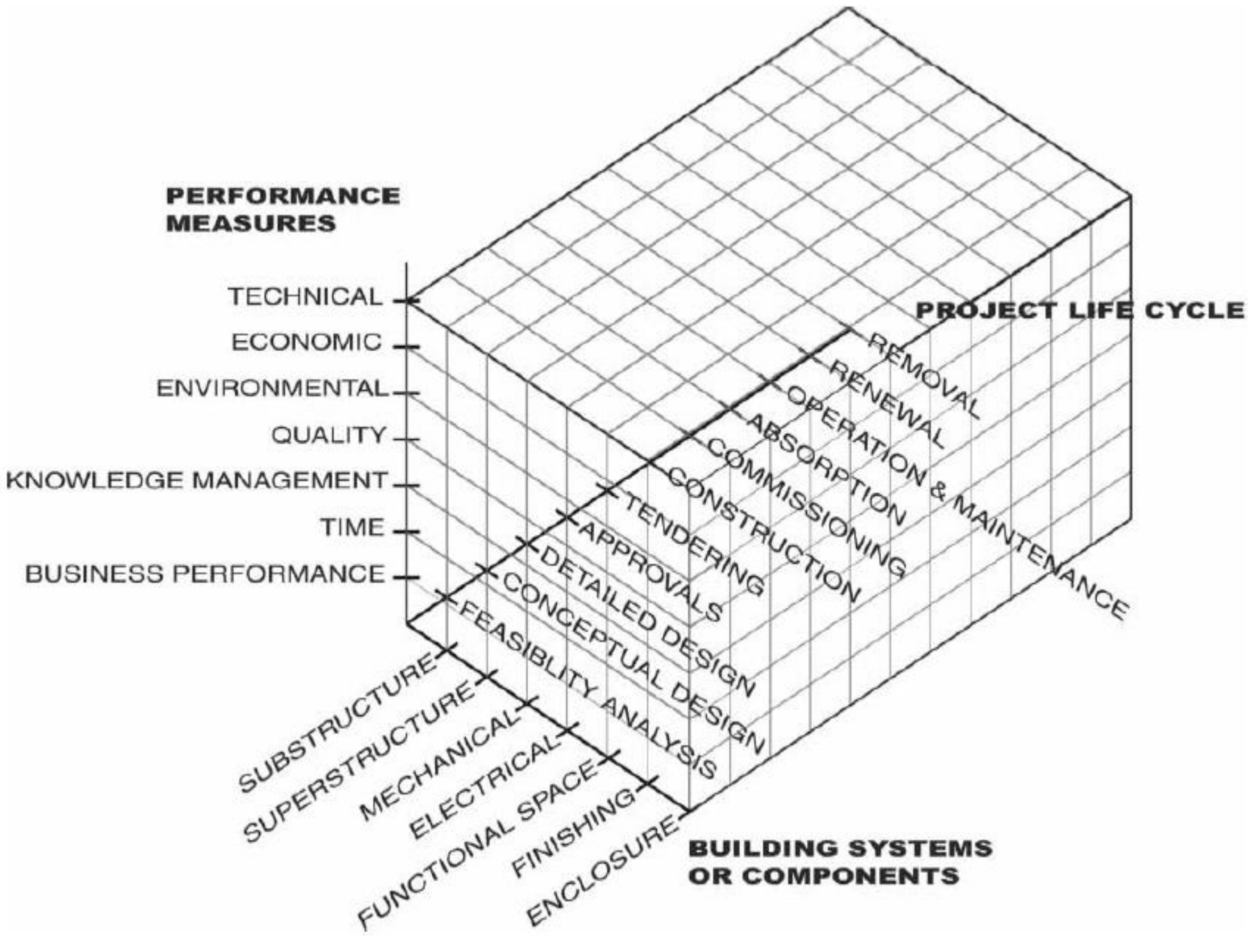

Figure 2.1.5: Three-dimensional structure illustrating a framework to assess sustainable building technology in multi-unit residential buildings (Nelms et. al. 2007, p. 240)

This Quantitative framework offers extensive development of specific categories and respective metrics well aligning it to action indication. However, this principally quantitative assessment, while quite complete, would likely prove unapproachable to most members of a community. This uniqueness could limit adoption toward sustainability by the larger Community, and only engage the players aligned and engaged with the framework developers. In that sense, another type of quantitative model is often applied where high-level goals for sustainability and efficiency are directly and simply communicated to players, as discussed in the next section where Quantitative approaches are combined with Goal Setting.

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Quantitative Types and Goal Setting

Quantitative frameworks are based in metrics and data collection, and are aligned for issuing action to specific desired outcomes. Often, when confronted with the complexity of sustainable decision-making, larger entities simply decide to set reduction and efficiency goals. This is an effective strategy as they clearly establish vision and goals, and can forge a plan to achieve action based resource sustainability initiatives. High-level vision with supporting staff and determined resources then accommodates required locality decisions to enable the vision as a large organization.

An example of this type of Quantitative application can be found with the United States Department of Energy (DOE). The DOE has a staff of over 127,000 employees continuously working to develop and apply new sustainable strategies, not only for their immediate operations but to commercialize technologies. The DOE applies a 'top down' approach by assessing current state for a specific set of metrics and establishes quantitative sustainability goals for their operations in their 2011 Strategic Sustainability Performance Plan. (US DOE 2011a, p. 5) Of particular note, with this example the DOE does not perceive that they are in competition with any other entity in the sustainability plan. The organization is so large that the overriding framework application must only establish the current state and specific quantitative goals to achieve the sustainability vision. This performance plan discusses expected reductions calibrated to a baseline, and return on investment as principle drivers to evaluate success.

As an independent entity with no competition, the DOE high level plan does not incorporate diffusion concerns in communities outside the immediate scope of their facilities which is unlike other competitive environments. This plan is more simply a quantified version of current state sustainability performance with consumption reduction goals in place. The Senior Sustainability Officer, Deputy Secretary of Energy Daniel B. Poneman, offers the following overview of the sustainability vision for the DOE:

"Sustainability is fundamental to the Department of Energy's research mission and operations as reflected in the Department's Strategic Plan. The mission of the Department of Energy is to ensure America's security and prosperity by addressing its energy, environmental, and nuclear challenges

through transformative science and technology solutions. We are implementing our mission through the following strategic goals:

- Catalyze the timely, material, and efficient transformation of the Nation's energy system and secure U.S. leadership in clean energy technologies
- Maintain a vibrant U.S. effort in science and engineering as a cornerstone of our economic prosperity, with clear leadership in strategic areas
- Enhance nuclear security through defense, nonproliferation, and environmental efforts" (DOE 2011a, p. 5)

The DOE plan presents a baseline assessment for current operations, which is reproduced below as table 2.2.1:

Table 2.1.1: 2011 Strategic Sustainability Performance Plan Current State (DOE 2011a, p. 7)

DOE performs its mission while operating in 47 locations across the U.S. with a Federal and contractor staff of over 127,000.

Total # Employees	127,376[a]
Total Acres Land Managed	2,300,000
Total # Facilities Owned	18,713
Total # Facilities Leased (GSA lease)	55
Total # Facilities Leased (Non-GSA)	446
Total Facility Gross Square Feet (GSF)	129,000,000
Operates in # of Locations throughout U.S.	47[b]
Operates in # of Locations outside of U.S.	N/A
Total # Fleet Vehicles Owned	3,928
Total # Fleet Vehicles Leased	11,180
Total # Exempted-Fleet Vehicles (Tactical, Emergency, Etc.)	835
Total Operating Budget FY 2010 ($MIL)	$24,425
Total # Contracts Awarded FY 2010	4,889
Total Amount Contracts Awarded FY 2010 ($MIL)	$20,671
Total Amount Spent on Energy Consumption FY 2010 ($MIL)	$401
Total MBTU Consumed per GSF	249.3
Total Gallons of Water Consumed per GSF	62
Total Scope 1&2 GHG Emissions (Comprehensive) FY 2008 Baseline $MMTCO_2e$	4.634
Total Scope 1&2 GHG Emissions (Subject to Agency Scope 1 & 2 Reduction Target)	4.622

Due to the broad geographic distributions and intricacy of large, complex organizations, sustainability goals are quantitatively expressed by measurable factors, and actions to achieve the vision and goals are assigned to local players to cover multiple projects and solutions. As is shown in table 2.1.2 reproduced from the DOE sustainability plan, goals are based on percentage reduction of measurable indicators over current state:

Table 2.1.2: 2011 Goal 1 DOE Planning Table (Strategic Sustainability Goal Planning Table) (DOE 2011a, p. 41)

	SCOPE 1&2 GHG TARGET	Unit	FY 10	FY 11	FY 12	FY 13	FY 14	FY 15	...	FY 20
Buildings	Energy Intensity Reduction Goals. BTU/SF reduced from FY03 base year)	%	15%	18%	21%	24%	27%	30%	...	hold
Buildings	Planned Energy Intensity Reduction. (BTU/SF reduced from FY03 base year)	%	17%	18%	21%	24%	27%	30%	...	hold
Buildings	Renewable Electricity Goals (Percent of electricity from renewable sources)	%	5%	5%	5%	7.5%	hold	hold	...	hold
Buildings	Planned Renewable Electricity Use (Percent of electricity from renewable sources)	%	9%	9%	10%	10%	11%	11%	...	hold
Fleet	Petroleum Use Reduction Targets (Percent reduction from FY05 base year)	%	10%	12%	14%	16%	18%	20%	...	30%
Fleet	Planned Petroleum Use Reduction(Percent reduction from FY05 base year)	%	5%	12%	14%	16%	18%	20%	...	hold
Fleet	Alternative Fuel Use in Fleet AFV Target (Percent increase from FY05 base year)	%	61%	77%	95%	114%	136%	159%	...	hold
Fleet	Planned Alternative Fuel Use in Fleet AFV(Percent increase from FY05 base year)	%	163%	hold	hold	hold	hold	Hold	...	hold
Fleet	(NEW) Senior Executive Fleet Replaced with Low-GHG, High Efficiency Vehicles (Percent replaced from FY08 baseline year)	%	-	100%	hold	hold	hold	hold	...	hold
	Fugitive Emissions	%	42%	45%	50%	hold	hold	hold	...	hold

Another example of this strategy as applied at Lockheed Martin, similarly structured as a ‘top down’ approach as the company is a significant supplier to the US Federal government. As with the DOE, no specific sustainability strategy framework appears in place. These current state and goal tables are much aligned with DOE formats, and are not reproduced here in the interest of efficiency. However, as presented in the Lockheed Martin materials (Meyers 2009), government suppliers are required, in many circumstances, to follow the DOE guidelines to drive sustainability initiatives and these goals are communicated through similar quantified tables.

In contrast, quantitative goals may be represented differently for smaller, more individually based sustainability efforts. These types of frameworks are categorized as Physical (Todorov 2009), and are discussed in the following section.

Physical Types

Physical framework types in practice are typically specific to a resource and predominantly localized geographically. The purpose of their use is to understand trends of sustainability assessment to quantify ‘real world’ potential causes and reduce uncertainty in theoretical models by focusing on physical measurement.

One concern with this approach is that intimate study of a particular resource and its respective variability is time-consuming and labor intensive. Accordingly, time spans required for framework operation can be lengthy and publication of results delayed. Thankfully, automization of data collection diminishes the impact of these constraint as in the case of the National Weather Service and many geographic information systems (GISs). Nevertheless, lead times for accurate observations and analyses remain a concern with Physical frameworks.

The use of Physical frameworks for sustainability has been focused mainly toward environmental assessment, and is driven by trends in historical data and resource availability. In some applications, Physical frameworks may also be used to extrapolate future outcomes and project the

impact of behavior modification. Typical uses of this framework type have been for water, energy, building design, recreation of habitat, atmospheric pollution, and toxicity. (Todorov 2009)

This approach, due to its nature and time demands, forces investigators to be as thorough as possible with the initial development. Hence, as a benefit Physical frameworks promote a greater participatory approach and interdisciplinary perspectives to those involved. An unintended but inherent consequence of physical data acquisition and processing is limitation to specific and potentially fragmented portions of the global sustainability system, and may constrain contribution to the holistic view of sustainability decision-making.

A well-documented example of a Physical approach is the Environmental Protection Agency assessment and publication of air quality and respective standards. These reports are indications of trends, and at times result in site-specific studies for a particular location and emissions cause. However, more typically these results are measurements of the physical system without clear diagnosis of the contributors to the current condition. Specific causes of sustainability concern can be challenging to identify as a focus of Physical studies is current state assessment rather than root causes. A risk then presented is that results are affected by a wide range of contributors that may confound the data through both internal and external variables. (Ostrom 2009)

From an 'actionable' perspective, systemic change can be dramatically delayed from both policy implementation and community adoption timeframes under Physical approaches, which hinder these types of frameworks to clearly establish cause and effect in a particular setting. Even in the case of the transportation sector, these assessments are based largely on quantitative assessments for average vehicles and emissions to calculate a factor contribution. As such, they are strictly based on physical observation rather than pictorial, strict quantitative, or conceptual models.

Although inherent disadvantages may prevent full use of this tool, physically based frameworks are valuable to compare variables for localities. Application of Physical assessment type concepts will be presented later in the results section of this work.

Conceptual Types

Todorov and Marinova explain that “this category of models is very broad and is linked to humanity’s waking up to the limits of its natural environment and the negative impacts that population and its development have been having on it. They started with the work of the Club of Rome (Meadows et al. 1971), went through the conceptualization of the implications from the use of nuclear weapon (“nuclear winter”, see Turco et al. 1983) and from ozone depletion and the ozone hole (Litfin 1994) to go through the various futurist scenarios such as the ones developed by the World Business Council for Sustainable Development (e.g. Speth 2004), to the work on global warming and climate change (e.g. IPCC 2007).”

As an example of Conceptual approaches, the Intergovernmental Panel on Climate Change (IPCC) continues to gain recognition as the foremost authority on conceptual level sustainability assessments. To demonstrate, the IPCC convened in Lima, Peru on June 23-25, 2011 specifically to discuss the importance of decision-making frameworks for use with a report on sustainability covering "Economic Analysis, Costing Methods, and Ethics". (IPCC 2012) Meeting outcomes were published in 2012, and they demonstrate that broad Conceptual models applied by educated and experienced macro-level thinkers are valuable to develop high-level concepts toward sustainability. As observedwith other non-disseminated or micro-driven frameworks and strategies, concepts are not adopted across the general public. Conceptual assessments offer general theory guidance but are not tractionable for an individual; meaning that Conceptually based strategy success is largely driven by an engaged players personal values toward resource sustainability. As in the case with this IPCC example, current Conceptual frameworks do not seem to directly and simply engage the majority of community members. Large-scale sustainability practice must be established for meaningful outcomes today and Conceptual approaches offer insight to those who can understand them, but little to others not involved (the majority). That said, this Conceptual communication could be effective to enable localized action albeit reactionary and possibly not strategic.

Another distinguishing characteristic of Conceptual frameworks is that they focus on long run scenarios, which may face potentially devastating outcomes. (Todorov 2009) Conceptual communication has been shown to generate motivation and participation by applying general

observations and adding a fear component. They have garnered some success by presenting a "Doom and Gloom" perspective that has shown to be effective across elusive generational groups. As Todorov and Marinova point out, "the majority of them contain a warning element and signals for alertness, in some cases [on the basis of] threats and fears. Many are also ideologically laden and have been played heavily on the political agenda, occasionally allowing stakeholders' participation. With emphasis on the global, concrete solutions for local problems have been difficult to find within the theoretical models and some implied consequences have been the cause of despair and ideological wars." (Todorov 2009)

As an example of this Conceptual approach, a wide array of arguments posed by environmentalists, 'green' business representatives, and politicians espouse active participation to prevent Global Warming (the 'believers' and 'non-believers'). Many contend that the world's population should live in fear, and accordingly do anything possible to reduce the production of greenhouse gases (GHGs). Others suggest that anthropogenic impacts on our environment are inconsequential to larger environmental cycles. Each of these arguments can be construed as opinion, and with that fault, the inability of this Conceptual approach to manage uncertainty has been their weakest link to drive sustainability action, and has fostered more extreme views such as the climate change Denialism (Begley, 2007) perspective.

With these divergent theories, Hoggan and Littlemore (2009) discuss the challenge of uncertainty inherent in Conceptual approaches, which is which is critical to establish trust and consensus within a Community (Rogers 2003). The following anecdote is reproduced from their 2009 work helps describe the Conceptual approach challenge:

> "We are standing at the edge of a cliff. Behind us is a considerable crowd, 6.7 billion people and counting, and below is a beckoning pool. Some people say that you can jump into that pool without risk. They say that humans have been doing so for ages without any problems. But others say that waves have been eating away at the foot of the cliff, causing big rocks to fall into the water. They say that the risk of jumping grows more frightening by the day. Whom do you trust?

That’s a tricky question because here, on the climate change cliff, some of the lifeguards are just not that qualified, some have forgotten entirely whose interests they are supposed to protect, and some seem quite willing to sacrifice the odd swimmer (or the whole swim team) if they think there is a good profit to be made in the process. That’s what this book is about: lousy lifeguards – people whose lack of training, conflicts of interest, or general disregard have put us all at risk of storming off the cliff like so many apocryphal lemmings.” (Hoggan and Littlemore 2009, p. 7)

At a minimum, while Conceptual assessments and communication do not often result in clear action, they do foster passionate debates that have affected policy on a global scale. As such, they are effective at capturing media attention to broaden the socialization and interest in sustainability issues across demographics and cultures.

Combined Approaches

The Todorov and Marinova overview of sustainability 'framework' types presents characteristics and classifications of sustainability communication tools and application sets segmented into four categories. However, a reality in framework application is that types are frequently combined. In the following examples, more detailed analysis reveals that applied methods and published results combine at least two of the aforementioned four base framework types. This is a natural result of iterative and practical learning as expanded in the works of Kolb and others. Kolb's theories help explain the emergence of combined approaches as a solution to limitations in framework development. His cyclic process consisting of four principle steps of participation in concrete experiences, observation and reflection about the experiences, forming abstract concepts , testing those concepts in new situations (1975) can be seen in prior work, as well as ISDMF development presented here.

Typically, Combined models arrive at a minimum of two objectives: (1) first, to introduce the topic under consideration, and then (2) defend the investigation recommendations and conclusions. The following framework reproduction from Nessa presents an example that combines Pictorial,

Quantitative, and Physical types into a single framework for sustainability strategy development. (Nessa 2006)

The following framework diagram as presented by Nessa, et. al. (2006) is an example of a Combined framework type for sustainability assessment within the "broader objective of lifting the understanding of sustainability assessment from the environmental-focused realm to a wider interpretation of sustainability. The suggested framework is based on three main categories: indicators/indices, product-related assessment, and integrated assessment tools. There is furthermore the overarching category of monetary valuation tools that can be used as a part of many of the tools listed in the three categories. The tools are also divided by their spatial focus and the level of nature–society system integration. Discussion focuses on if and how the tools fulfill the objectives from the more current understanding of sustainability assessment." (Nessa 2006, p. 499)

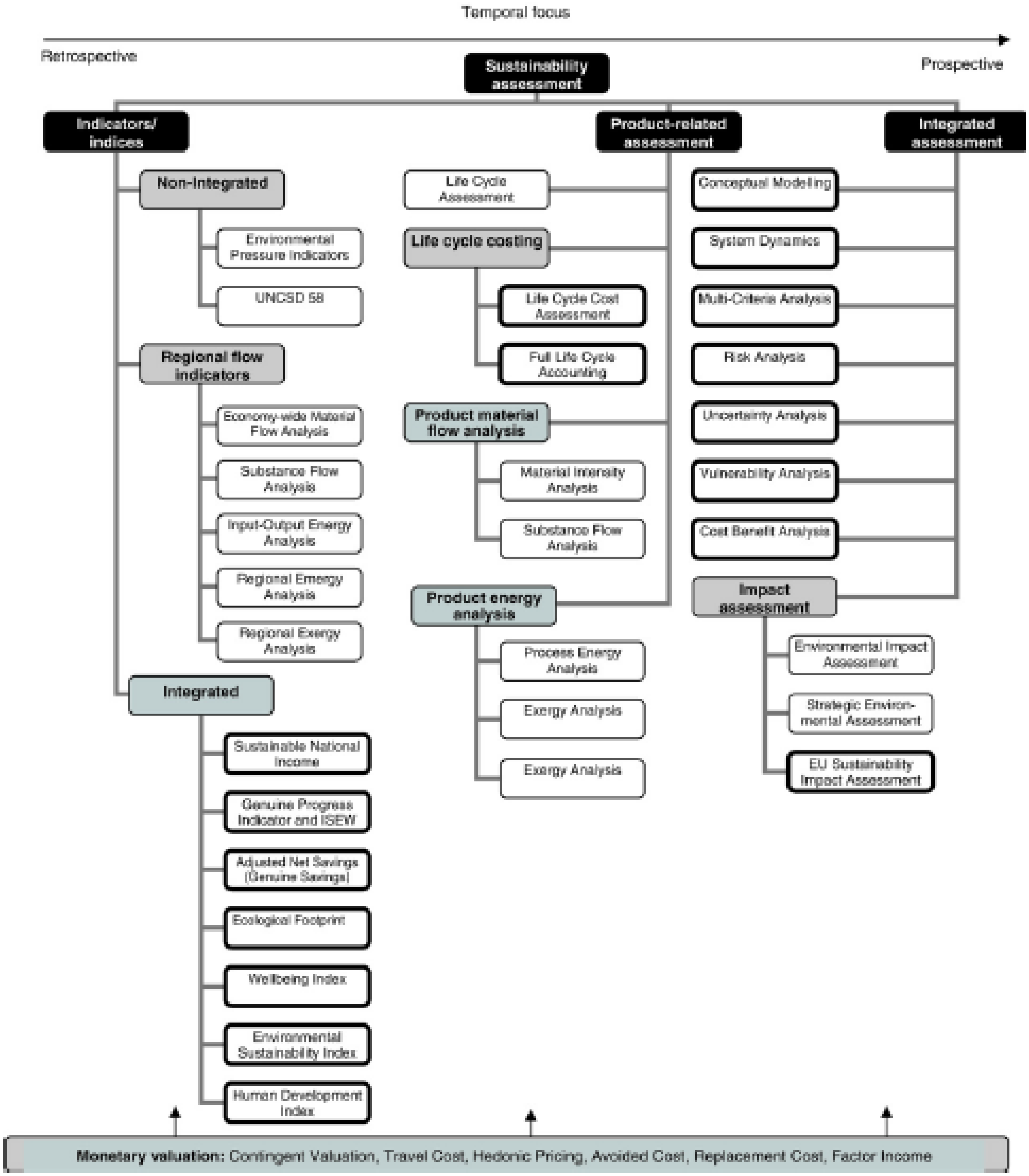


Figure 2.1.6: Framework for sustainability assessment tools (Nessa 2006, p. 500)

To describe the use of the above figure, Nessa included the following descriptor to better understand the approach: "The proposed assessment tool framework is based on the temporal focus of

the tool along with the object of focus of the tool. The arrow at the top of the framework shows the temporal focus, which is either retrospective (indicators / indices), prospective (integrated assessment) or both (product-related assessment). The object of focus of the tools is either spatial, referring to a proposed change in policy (indicators/indices and integrated assessment) or at the product level (product-related assessment). The monetary valuation tools on the bottom are used when monetary valuations are needed in the above tools. Thick lines around the boxes mean that these tools are capable of integrating nature-society systems into a single evaluation." (Nessa 2006) While not graduated in the diagram, Nessa implies the use of metrics, various populations of interlinked factors, and at the top of the figure includes a simple pictorial relationship between factors and timing (metrics) which is aligned with a Conceptual approach.

Two observations become apparent when comparing framework categories to this Nessa Combined approach: (1) Pictorial and Quantitative framework types are addressed, but (2) the physical and Qualitative types are not included. This blended approach converges toward a Quantitative and Goal Setting type, but remains ambiguous by identifying goal categories and not setting specific metrics with reference points. Most likely, this framework effort will only be embraced by those immediately and directly involved as more general participants will be challenged by it and consequently ignore findings from framework application As a result, this combined approach broadens affect but remains captive to a particular perspective (the originating group) and subject matter.

Another example of large-scale combined approach application is the Millennium Ecosystem Assessment (MEA) suggested by the United Nations Secretary-General Kofi Annan in 2000. Initiated in 2001 and operated through 2005, the objective of the MEA was to assess the consequences of ecosystem change for human well-being and the scientific basis for action needed for conservation and sustainable resource use. The MEA involved the work of more than 1,360 experts worldwide. Their findings, contained in five technical volumes and six synthesis reports, provide a scientific appraisal of the current condition and trends in the worlds ecosystems, services they provide (such as clean water, food, forest products, flood control, and natural resources), and options to restore, conserve or enhance the sustainable use of ecosystems. (MEA 2005) The MEA framework is reproduced below:

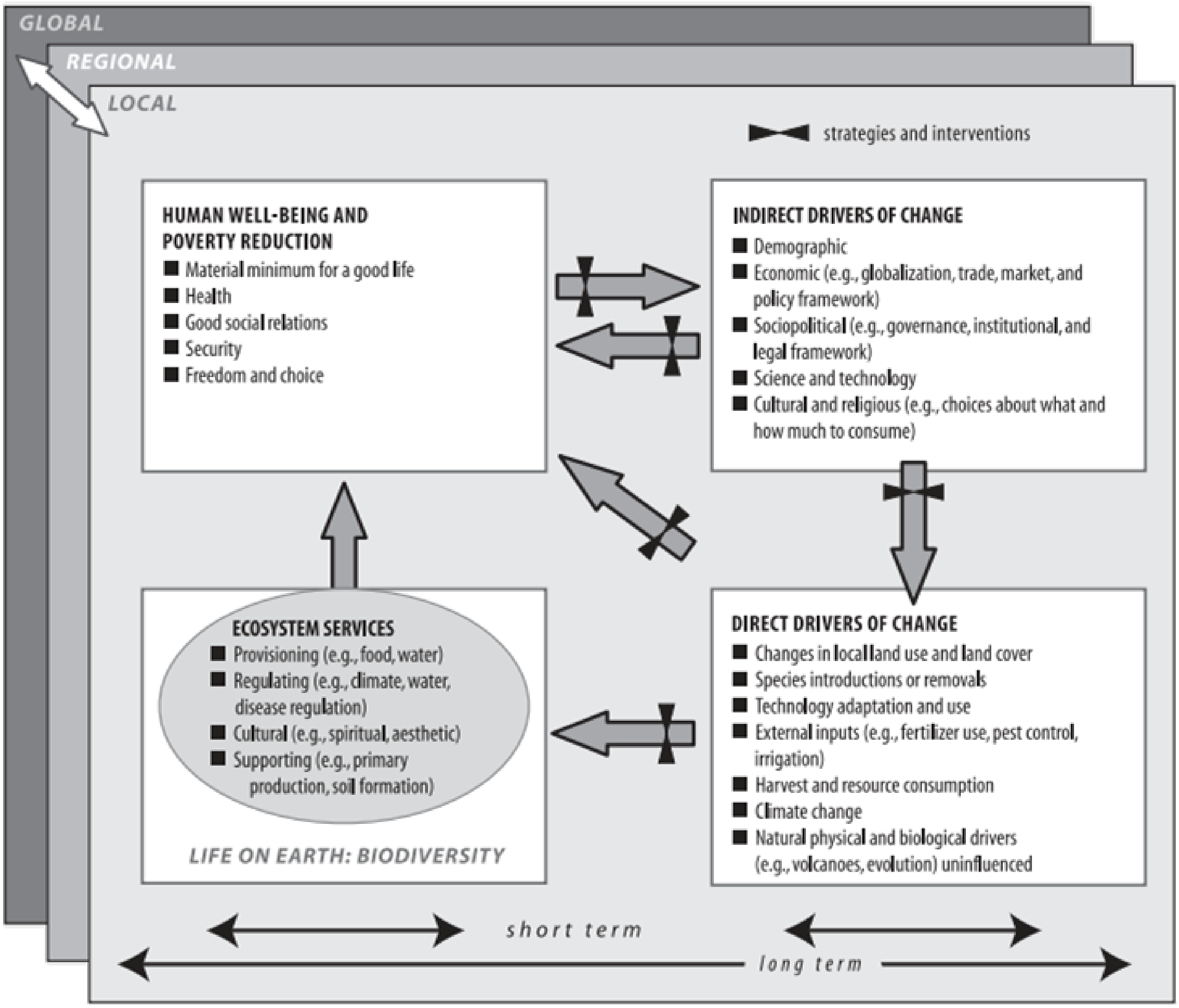


Figure 2.1.7: Millennium Ecosystem Assessment Conceptual Framework (MEA 2005a, p. vii)

The MEA explains that the change to ecosystems during the past half-century has been more rapid than any comparable period in human history. They also determined that while these changes have led to substantial net gains in economic development and human well-being, these developments "have been achieved at growing costs in the form of the degradation of many ecosystem services, increased risks of nonlinear changes, and the exacerbation of poverty for some groups of people. These problems,

unless addressed, will substantially diminish the benefits that future generations obtain from ecosystems.” (MEA 2005, p. 5) The MEA efforts represent a blend of Conceptual and Physical framework approaches and incorporates fear as a primary means to motivate public attention. These types of approaches are valuable to promote general public interest, but unfortunately are not thorough in providing clear actions to drive sustainable decisions across larger market segments not involved with the direct MEA efforts.

Another globally supported, Combined framework was coordinated by the United Nations Organization for Economic Co-operation and Development (OECD) unit, with actual framework development created by the U.S. National Academies. This framework was solicited by the OECD to support the U.S. Environmental Protection Agency and create a global framework benchmark for communication through the United Nations. These organizations continuously invest in sustainability workshops and development of globally sustainable solutions, and recently published their combined Sustainability Framework (NASF) in 2013. (OECD 2013)

The OECD Sustainability Framework is described in their literature by applying two levels of Todorov and Marinova categories: First, Pictorial and Quantitative framework characteristics are blended to provide framework 'high-level baseline' structure as an introduction, which is reproduced as figure 2.1.8; Secondly, references to Quantitative and Physical approaches are incorporated to provide a more refined view for application as presented in figure 2.1.9. This framework approach by the National Academies illustrates development and structure which is most similar to the ISDMF presented herein. Fully 70 percent of the topics align between the NASF and ISDMF, and the framework element sequence is nearly identical between the two. This comparison is presented in detail in the Results section, and the NASF is reproduced below in figure 2.1.8:

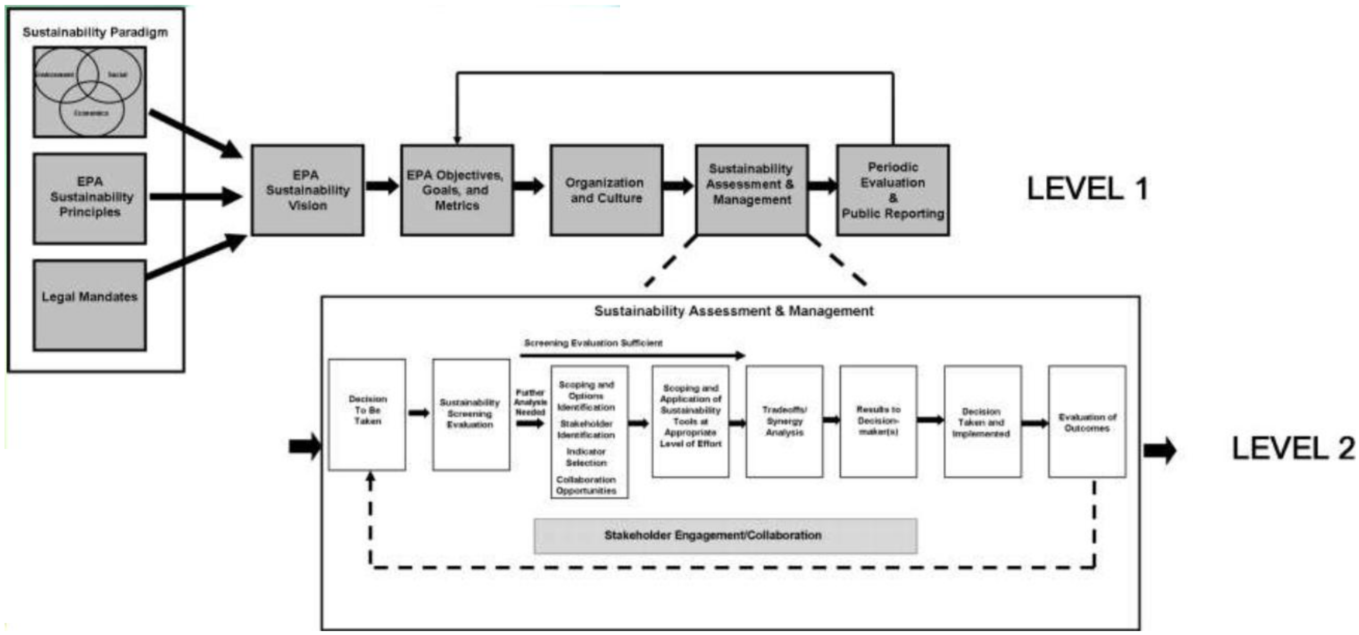


Figure 2.1.8: OECD Sustainability Framework (OECD 2013a, p. 16)

Of specific interest, in figure 2.1.8 and enlarged in 2.1.9, note that between boxes two and three of the Level 2 review, the NASF indicates "Further Assessment Needed". (OECD 2013a, p. 16) Detailed discussion of this example is presented in the Results section.

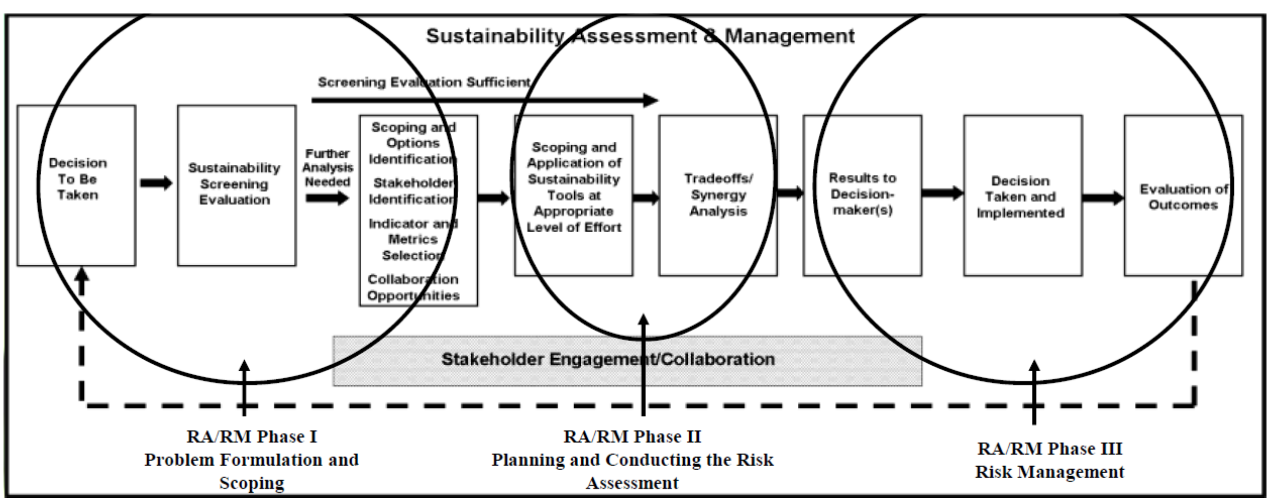


Figure 2.1.9: OECD Interface between Risk and Sustainability (OECD 2013a, p. 27)

In both the MEA and NASF examples, framework development investment and manpower demonstrate inherent complexity of current sustainability framework use. Within these Combined type framework examples is illustrated the observation from Kates discussed in section 1.3.1: Inner workings of coupled human-environment systems drive rapid proliferation of framework size and complexity. (Kates 2011)

Summary of Identified Frameworks and Types

Throughout this section are presented a means of categorizing the prior work, examples of described framework types, and general discussion of each. All offer intrinsic benefits toward intended purpose and audience, but none of the four established, basic framework types excels in all areas of utility to be an 'optimal' framework. As discussed in the Introduction, effective frameworks must (1) be **approachable** by the community, and (2) be **actionable**, meaning that the assessment provides clarity to specific sustainability decisions to enable effective solutions through action, and (3) be **adoptable** by the majority of the community to achieve desired strategy effect.

Combined approaches seem to incorporate benefits from more basic framework types, and two published frameworks similar to the Integrated Sustainability Decision-Making Framework were found (from the MEA and National Academies) for more detailed comparisons in the Results section. Per the Todorov and Marinova definitions and extensions in this work, current frameworks are well suited to two of the three sustainability factors of approachability, action ability, and / or adoptability. However, only Combined approaches can sufficiently support all three sustainability framework utility factors simultaneously.

The figure below compares the identified framework types and is reproduced from the Introduction for convenience. Note that combined approaches are not included in the chart as they are hybrids designed to maximize all three sustainability factors (identified in the upper right hand corner as the desired framework utility).

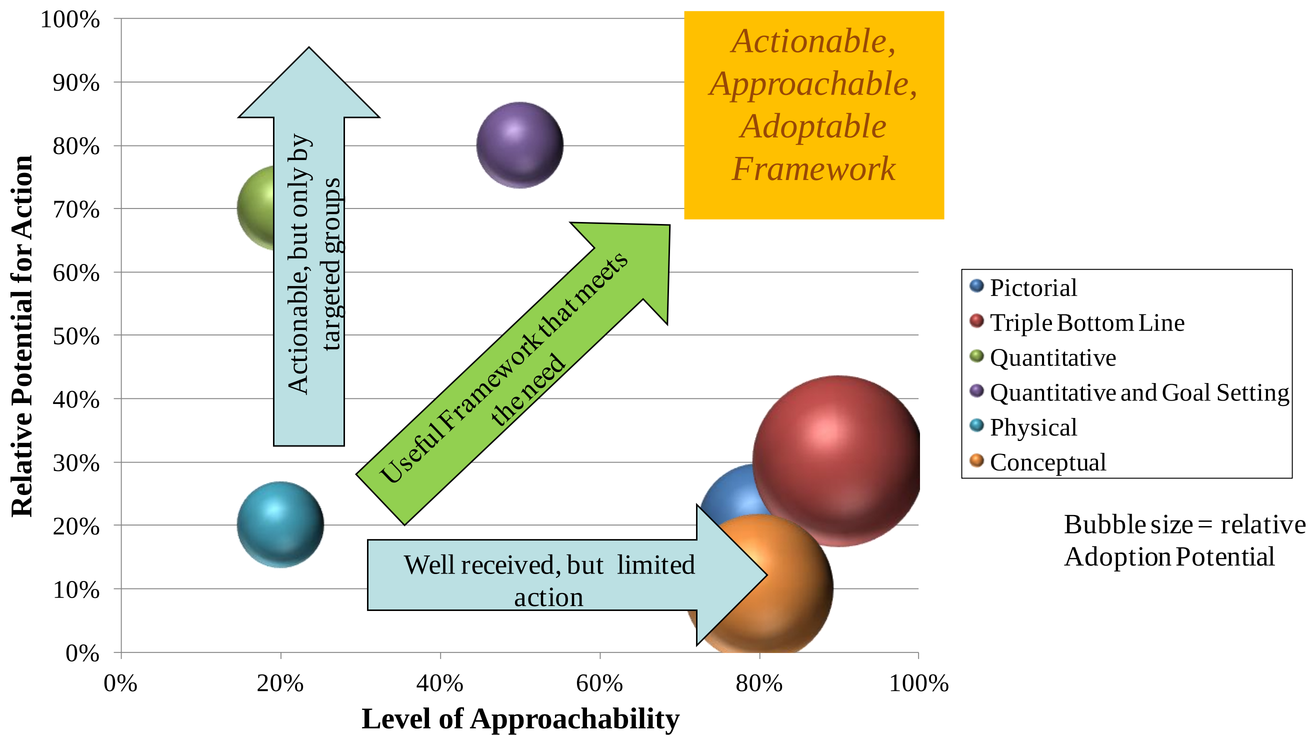


Figure 2.1.10: Comparison of Relative Approachability, Actionability, and Adoptability of Frameworks

2.2. Elements of an Approachable Framework

As presented in section 2.1, a broad collection of frameworks are continuously developed and applied to the art of sustainability management. Each type of framework offers distinct benefits and drawbacks when communicating information to foster sustainable decision-making. Prior framework assessment highlights that two basic themes exist, at a minimum, to enable widespread community involvement: (1) The population must be aware and educated of options available, and (2) make the most appropriate decision to preserve or improve Quality of Life.

Any viable decision-making process must then be approachable by a significant segment of a community, understood, and implemented through specific actions an individual participant can take to improve. While it is ideal to think that all members of the Community operate autonomously, rationally, and select optimal sustainability decisions for holistic improvement, very often actions are taken based

on individual benefit combined with the observed actions of others. (Rogers 2003) Socialistic behavior introduces themes of competition and cooperation between players, which must also be considered when designing a sustainability strategy.

The following subsections provide summaries of foundational theories referenced in the process flow representation of the ISDMF in the Introduction. Again, the ISDMF is a check list for sustainable decision-making and is based on the prior works presented in this Literature Review. Many of these contributors are prolific experts and authors, and are selected and discussed here to further define the ISDMF and as excellent starting points for users to understand the process steps involved with sustainable decision-making. Concepts are summarized to the extent possible and still provide an introduction to the foundation and intent of the ISDMF process steps. Sustainability decision-makers are encouraged to incorporate additional references as further support of process steps when needed.

Within the ISDMF Current State evaluation player behavior is considered across individual, competitive, and cooperative participation among resource chain participants.

2.2.1. Current State and Individual Behavior of Players – Michael Porter's Five Forces

Michael Porter published his widely accepted Five Forces analysis in 1979 as a framework to understand the attractiveness or profitability of an industry from a strategic perspective. His work is a valuable means to understand and categorize competitive forces that govern the behavior of a participant for a specific, rivalrous marketplace. While not typically applied to sustainability, Porter's work presents a valuable first means of assessing barriers, opportunities, and behaviors that may affect sustainability. Porter's Five Forces That Shape Industry Competition framework is reproduced below:

Figure 2.2.1.1: The Five Forces That Shape Industry Competition (Porter 2008, p.27)

Porter suggests that all Five Forces exist in an industry micro-environment, indicating an assumption that the Forces be considered specific to a particular industry and players capable of competing directly. When his concept is applied to sustainability evaluation, three Forces refer to competition from external sources (Bargaining Power of Suppliers, Bargaining Power of Buyers, and Threat of Substitute Products or Services), and the remaining two factors are directly related to the industry and internal to the competition (Threat of New Entrants and Rivalry Among Existing Competitors). (Porter 2008) While application of Porter's Five Forces framework is geared toward evaluation of a given line of business industry, the localized nature of rivalry provides a basis to craft an initial, individual assessment of players in the resource sustainability decision-making process.

Application of Porter's Five Forces to resource sustainability assessment requires factor definitions as intended by him; however, his strict consideration of competition within a specific

industry is reoriented in this work to more directly apply to resources that are rivalrous and pose depletion risk. This consideration implies that the Porter Five Forces approach is not only considered from industry or 'provider' perspectives, but also from the 'Community' or consumer perspective as an extention to his original work. With this adaptation, assessment not only considers industry competition but also includes market as a significant contributor to outcomes, which Porter generally identifies as a 'substitute' force.

For example, while a water or electricity utility would likely only contemplate competition from other utilities, profitability and revenue can also be greatly affected by community adoption of conservation measures, or perhaps investment in distributed electricity generation from solar, wind, or other technologies as resource enablers. From that perspective, the following description of Forces outlined Porter's work would take the following modified form for sustainability assessment:

Bargaining Power of Suppliers – Traditional resource delivery models often place a regulated utility as a supplier to the end customer. This differs from the more widely applied consideration of suppliers for competitive strategy analysis using the Five Forces. In the Porter definition, suppliers are viewed as the providers of needed commodities in a given industry such as raw material, components, labor, and services. In that sense, suppliers hold power over resource system participants when few substitutes exist. With incumbent and monopolistic utility controlled resource delivery, a parallel can be drawn with the famed Sharecropper model where entire farming communities were captive to a single landowner who also conveniently owned the land and often a 'community' supply store. As a base supplier to the 'tenant' community, the landowner / retail seller can operate on anticipated credit with the tenants and set supply prices at such high rates that the sharecroppers always ended the season indebted to the landowner / storeowner. Historically, utilities could operate under this scenario but these risks were identified and policies were developed and implemented to prevent this behavior.

Threat of New Entrants – Attractive markets entice new entrants to benefit from profit opportunity, which can lead to increased competition and pricing battles. Over time this can work in

favor of consumers and to the detriment of industry firms as profit margins may migrate to zero or 'perfect competition'. Typically with modern resource production and delivery, strong 'natural' monopolies wholly own all resource distribution infrastructure which virtually eliminates new entrants in a given market. For this reason, these markets are highly regulated based on resource access requirements of the community. However, increasing incidence of free market pricing approaches, more technologically viable distributed resources, and financial models (like third party leasing arrangements) allow consumers to enable new providers to enter the game for a given resource.

Bargaining Power of Buyers – This Porter framework 'Force' considers the ability of customers to apply pricing pressure or not purchase at all. While discussed in later sections of this work, often resource delivery is highly regulated and resource chain participants engage in lengthy processes of commodity rate negotiation and issuance. However, as technology options advance in the marketplace and affect prices customers are willing to pay for a given resource they may opt to invest in alternative technologies to place pressure on incumbent pricing or service.

Threat of Substitute Products or Services – This 'Force' can be summarized as a market dislocation through innovation, and encourages customer migration away from an incumbent product or service to meet a similar need in an entirely new way. In resources terms, an example would be a consumer that stops purchasing gasoline for a vehicle and instead uses public transportation. Generally, one could summarize the concept as products or services outside the current product boundaries which allow or encourage customers to migrate to innovative alternatives.

Rivalry Among Existing Competitors - For many industries, the intensity of competitive rivalry can manifests itself in many ways to enhance consumer value. As Porter points out, competitors may engage in "price discounting, new product introductions, advertising campaigns, and service improvements" to enable markets. (Porter 2008, p. 32) His observation identifies that industry profitability is then inversely proportional to the number of players, market size, and capability of each

competitor for long-run competitiveness. This concept is suited to resource management, as effort to create sustainable adoption is largely based on pricing and consumer access to alternatives.

While not explicitly considered as a Force in Porter's framework, an underlying element is the concept of Environment in sustainability analyses. Environment in this application refers not only to the physical world (air, water, temperature, etc.), but also to regulatory or even community perception that can affect player behavior in the resource chain. As an example, regulatory environment dictates acceptable operating profit for utilities while simultaneously supporting substitute technologies through subsidies. The concept of Environment as a Quality of Life measure can be further extrapolated to suggest that these factors enable or restrict actions observed through the application of Porter's Five Forces framework.

Porter has continued to advance his work over the past decades, and now recognizes that the inclusion of sustainability presents an additional factor (Porter 2011) to his original Five Forces framework. With his publication "Creating Shared Value: How to reinvent capitalism—and unleash a wave of innovation and growth", Porter discusses a theory of "Shared Value" that must also be considered beyond his original Five Forces framework when creating sustainable strategies. In his article (2011), he states that "we still lack an overall framework for guiding these efforts, and most companies remain stuck in a "social responsibility" mind-set in which societal issues are at the periphery, not the core." (2011, p. 64)

With these sustainability based adjustments to Porter's Five Forces framework, the modified Five Forces provides a basis for individual motivation determination and offers insight into the more holistic view of "Shared Value". Perhaps one of the more profound observations in his work is that "Shared value creation will involve new and heightened forms of collaboration" (Porter 2011, p. 76). This work supports his observations by presenting a framework designed to facilitate ongoing sustainable decision-making by including recognition of increased collaboration in competition between players which is developed in the following subsections.

2.2.2. Current State and Two Player Game Theory – A General Consideration for this Study

With individual motivations and an initial approach to organize them defined using Porter's Five Forces, the ISDMF now considers interplay of participants in competition. Individual decision-making is a core component of this work, and establishes a basis for the assessment of individual motivations in a competitive environment. This subsection section carries unique individual motivations among players into a dual player game to evaluate competition in the sustainability chain if present. Porter's work does not delve into game theory as development for specific scenarios, but poses the broader importance of certain game theory concepts to review interactions between players.

Within that scope, two basic game theory topics are relevant for resource decision-making and actions among the myriad of approaches. The first core element suggested, and perhaps most paramount, is access to information. The second is how, with the availability and access to information, formed game structures enhance individual player positioning as 'competition'.

This work entertains the relevance of game theory in a general sense. Game theory is a complex science, and is only introduced here as a starting point to advance the practical application of the presented ISDMF. As stated in the Introduction, the essence of this work is the integration of philosophical tools and concepts to offer a structure that enhance sustainability decision-making efficiency resulting in Quality of Life improvement. Within this context, the following sections strive to further describe a second level of resource sustainability consideration based on competitive elements as the Define Competition Between Players step in the ISDMF.

Resource Game Theory General Consideration 1: Complete versus Incomplete Information

Preliminary work to create the ISDMF suggests that individuals must be (1) aware and (2) have knowledge to select options and fully enable beneficial action. Optimized decisions likely can not be made without the best available information. This assumption suggests that a major component to determine the best sustainability path is based on information access and use among the players. On a macroscopic basis, strategy development using the ISDMF must consider the influence of information availability as a competitive element to promote or detract from sustainable outcomes.

Ostroms body of work is a key reference to understand this topic, and offers insight toward informed decision-making within two player game theory. A principle reference to understand game theory related to resource management is presented by Ostrom in Governing the Commons (1990, p. 4). In that work, she introduces game theory by using the example of two herders grazing animals on a shared, fixed plot of land.

In Ostroms example, the number of animals supported on the given land is L. Each of the two herders is allotted equal access to the land, and allowed the same number of supportable animals or L/2. This scenario allows each herder sustainable access to the land and the ability to maximize profit. As illustrated below in figure 2.2.2.1, if two players actively participate in a cooperative relationship each player earns an profit of 10 which is the maximum allowed when considering the constrained resource (land). In the analysis, Ostrom denotes 'C' as player Cooperation or adherence to the agreed strategy, and 'D' as Defection from the strategy. If a single player defects, only slightly incremental gains are realized by the defector (+1 or 11) while the other player or "Sucker" (Ostrom 1990, p. 4) suffers a profit loss (-1). Finally, if both players defect from the strategy they each receive zero profit as overgrazing would occur and both suffer losses against profit potential. Ostrom calls this two player game the Hardin Herder Game, also known as the 'Prisoner's Dilemma' or 'Tragedy of the Commons', which will be discussed in subsequent sections. Here, it is presented as a basis of game structure, assumptions, and the role of cooperation and defection for the various game scenarios presented.

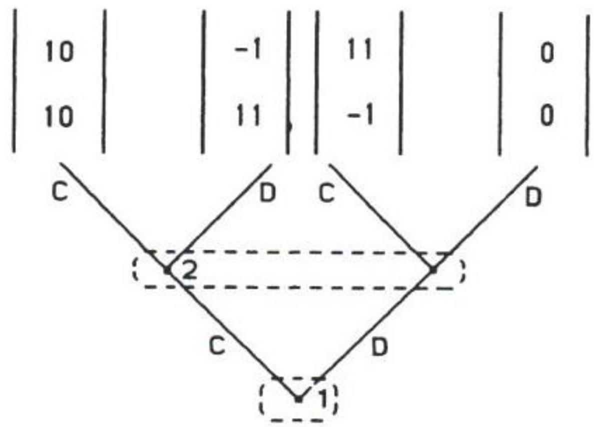


Figure 2.2.2.1: The Hardin herder game (Ostrom 1990, p. 4)

From the Hardin Herder game, an expansion can be made to a more realistic resource management scheme applicable to modern society. Often community resources are exposed to a central authority structure, and the above elementary game theory construct moves to incorporate the impact of a central authority that establishes penalties for defection through policy. At a high level, two models exist where complete information is known and another where a single or series of players are uninformed. Ostrom designates that each model exists under a central, governing authority to constrain assumptions. She expands the theory to exemplify that players operating with communicated, complete information have a better opportunity to benefit from action beyond a game where players are not fully informed of each players position. As was discussed in the Individual section with Porter theories, this game consideration illustrates the need for each player to understand the anticipated behaviors and positioning of all involved which implies the need for full transparency.

As the Hardin game is expanded to include central authority involvement, Ostrom presents the following diagram based on the Hardin herder game definitions to describe a more complex central authority game with complete information:

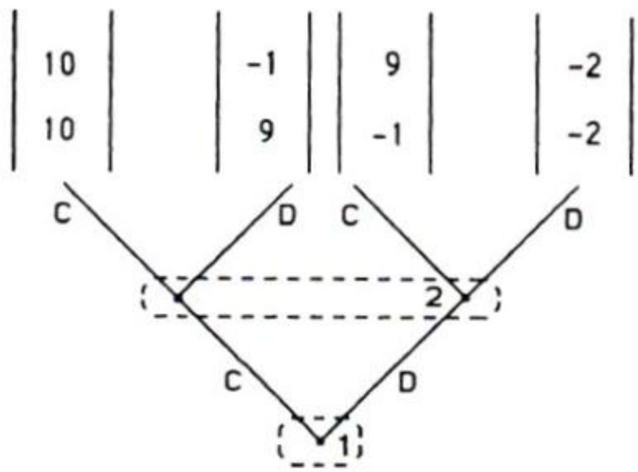


Figure 2.2.2.2: The Central-Authority Game with Complete Information (Ostrom 1990, p.10)

The general structure suggests that if a fully informed and accurate policy or agreement is in place and adhered to, each player will receive 10 units of profit assuming negligible administrative cost. In the case of one player cooperation and one defection, the defecting player loses 10% or -1 as they gain initial profit through defection but are penalized through the central authority by -2 profit units. The other cooperative player will be penalized by -1 or a 10 percent loss of potential profitability for the defector for not complying with the agreed structure and reducing the strategic potential. Each level of penalty is indicated by dashed lines in Ostrom's reproduced illustrations. Finally, if both players work against the determined policy under central authority that properly imposes penalties, the profit is depleted fully and both participants suffer a -2 or 20% loss each through central authority punishment. Ostrom points out that this game is based on the assumptions of "accuracy of information, monitoring capabilities, sanctioning reliability, and zero costs of administration" (Ostrom 1990, p. 10).

This central authority governed, two player example defines a baseline to expand into the larger consideration of two player game theory related to awareness, education, and adoption. As presented, a centralized, fully communicated and adopted policy platform can yield substantial returns to players who are actively involved and co-operate with prescribed sustainable resource solutions. Through Ostrom's assessment of fully informed cooperative or defective behavior, a foundation for the larger

point can be discussed: The importance of full disclosure and communication between players when making strategic resource decisions and taking actions. The resultant observation is that players must be willing to disclose all relevant information, and comply with a negotiated practice of resource use.

In the next example, the impact of incomplete or inaccurate information is assessed. Ostrom describes and evaluates incomplete information as relevant to the central authority enforcement of penalties against players, but with complete information to develop initial policy. In her work, information made available for policy and penalty development is not available or used, and accordingly the governing authority does not have complete information to accurately assess operational penalties. The probability 'y' is used to assess the likelihood of punishing defectors, and accordingly '1 - y' is the probability of not punishing defectors. Ostrom also assumes that 'x' indicates the probability of erroneously punishing cooperative action, and '1 - x' is the probability of not punishing cooperative action.

In the reproduced game model, a comparison can be made to determine the impact of information deficiency from two perspectives to include enforcement and the policy itself.

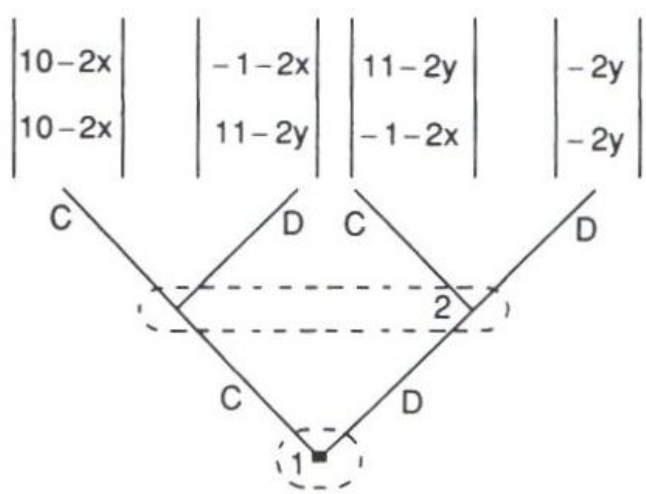


Figure 2.2.2.3: The Central-Authority Game with Incomplete Information (Ostrom 1990, p.11)

To demonstrate the impact of these information issues, as an example Ostrom assumes that the central authority imposes both types of sanctions correctly with a probability of 0.7 making x = 0.3 and y = 0.7. The results are shown in figure 2.2.2.4 below:

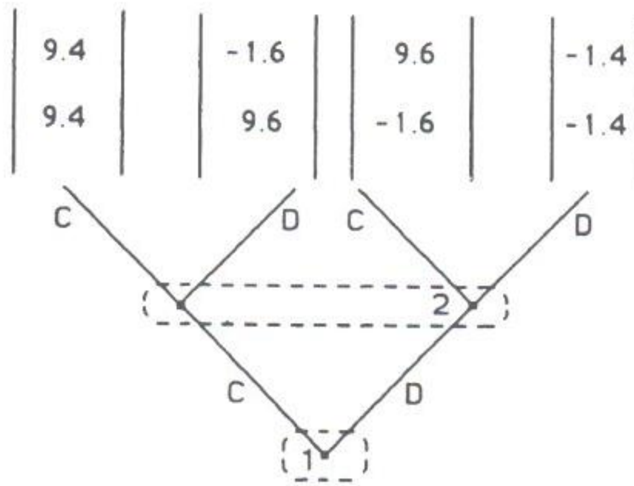


Figure 2.2.2.4: Example of The Central-Authority Game with Incomplete Information (Ostrom 1990, p.11)

From this example, incomplete information is shown to have two core effects: First, players cannot achieve the maximum strategic profit of 10 because the policy in place and information available to the central authority is not optimized. Full cooperation without complete information has an equilibrium of 9.6, which is lower than the regulated game with full information and cooperation. Second, the probability of imposing full and accurate penalties is reduced, which could result in greater player motivation to defect. This reduction of penalty risk 'if caught' could motivate a player to overuse the given resource and marginally increase profit at the expense of the other player. This leads to the Hardin Herder Game which threatens players when competing for rivalrous and depletable resources, which is discussed in greater detail in the following section.

Resource Game Theory General Consideration 2: The Threat of Rivalrous and Depletable Resources

Historically many concepts have been applied to unravel the complexity of sustainable resource solutions. One widely referenced attempt to clarify the challenge of equitable resource utilization was proposed by Garrett Hardin through the 'Herder Game' in 1968 with his essay "Tragedy of the Commons." In his work, he expanded the concept of inherent drive by an individual to work toward personal advantage at the expense of the long run resource sustainability of the community. (Hardin 1968) The earliest identification of this conflict of between individual behavior versus community benefit creating detrimental outcomes was originally postulated by William Forster Lloyd in his 1833 publication 'Two Lectures on the Checks to Population'. Lloyds work is the original reference to "Tragedy of the Commons", and introduced the concept of diminishing marginal utility and connecting demand to value. The general theory is that an individual will most benefit from incremental consumption of a finite resource for a positive benefit when the life cycle cost of the investment will be distributed across the community or 'commons'. (Lloyd 1833)

This two player game theory can be considered for a wide array of resources. As an example, the nexus of water and energy production with their respective environmental impacts. In these cases, regulatory agencies are installed to govern pricing and pollution to control the Hardin Herder Game risk. In the absence of effective governance, private and public utilities would work to operate as profitably as possible by exploiting 'commons' and pushing their operating costs to the general society. For this reason, the two player Tragedy of the Commons or Prisoner's Dilemma behavioral model is referenced here as another game theory application starting point for users to consider when creating a sustainability strategy.

An explanation through example was presented in Elinor Ostrom's 1990 publication Governing the Commons (p.217), as supplementary information and support:

:

> "Attributed to Merrill M Flood and Melvin Dresher and formalized by Albert W. Tucker (R. Campbell 1985, p. 3), the game is described (Luce and Raiffa 1957, p. 95) as follows: "Two suspects are taken into custody and separated. The district attorney is

certain that they are guilty of a specific crime, but he does not have adequate evidence to convict them at a trial. He points out to each prisoner that each has two alternatives: to confess to the crime the police are sure they have done, or not to confess. If they both do not confess, then the district attorney states he will book them on some very minor trumped-up charge such as petty larceny and illegal possession of a weapon, and they will both receive minor punishment; if they both confess they will be prosecuted, but he will recommend less than the most severe sentence; but if one confesses and the other does not, then the confessor will receive lenient treatment for turning state's evidence whereas the latter will get 'the book' slapped at him. In terms of years in a penitentiary, the strategic problem might be reduced" to the following:

Table 2.2.2.1: The Prisoner's Dilemma (Ostrom 1990, p.217)

	Prisoner 2	
Prisoner 1	Not confess	Confess
Not confess	1 year each	10 years for prisoner 1 3 months for prisoner 2
Confess	3 months for prisoner 1 10 years for prisoner 2	8 years each

Cooperation and commitment to the Not Confess strategy offers greatly reduced total penalty to each prisoner, whereas defection through confession by either one or both greatly increases the total prison time. This relationship illustrates the need for players to maintain common intentions and information. When applying this concept to a community strategy, if defectors are allowed to continuously benefit from marginal gains at the expense of others, the entire group will suffer greater consequences in the long run.

With this understanding of the importance of cooperation for more sustainable solutions, consider the Prisoner's Dilemma focused toward the sustainable management of resources. As in the

case of prisoners, cooperative and active participation allows an entire community rather than an individual to benefit over time. Peter Senge presents a real world example in his comprehensive work the Fifth Discipline published in 1990. He reviews the case of the Sahel region in sub-Saharan Africa and the impacts of individual, logical behaviors that resulted in tragedy for the entire community. Reproduced from page 294 of the Senge's Fifth Discipline:

> "For example, the Sahel region in sub-Saharan Africa was once a fertile pastureland. In the middle of this century, it supported over a hundred thousand herdsmen and over a half million head of grazing cattle (called "zebu"). Today, it is a barren desert, yielding a small fraction of the vegetation it produced before. The people left there scratch out a meager existence under continual threat of drought and starvation.
>
> The tragedy of the Sahel was rooted in steady growth of population and herd sizes from the 1920s to the 1970s. The growth accelerated from 1955 to 1965 due to unusually heavy rainfalls and assistance from international aid organizations who financed and numerous deep wells. Each herdsman on the Sahel had incentives to expand his herd of zebu, both for economic gain and social status. As long as the common grazing lands were large enough to support these new, larger herds, there were no problems. But in the early 1960s, overgrazing began to occur. Eventually rangeland vegetation grew sparser. The sparser the vegetation, the more overgrazing, until it got to the point where the cattle consumed more foliage than their ranges could generate. The desertification reinforced itself as decreases in plant cover allowed wind and rain to erode the soil. Less vegetation was produced, which got overgrazed more severely to support the herds, leading to further desertification. The vicious spiral continued until disaster struck in the form of a series of droughts in the 1960s and 1970s. By the early 1970s, 50 to 80 percent of the livestock was dead and much of the population of the Sahel was destitute." (Senge 1990, p. 294)

This example presented by Senge is a real world demonstration of the Tragedy of the Commons game. When individual participants operate with logical motivations for personal benefit and disregard the impact to the community as a whole, all are at risk of catastrophic long run impacts and and even marginal benefits may not be sustainable.

Finally, regarding the two player Tragedy of the Commons game, many economists argue that property rights can eliminate the conflict of commons usage. While this observation has some validity in the strict application of some resources such as grazing pastures, most resources flow between property boundaries and cannot be easily attributed to a particular owner. These resources can be visualized by considering air quality, water availability, primary (natural gas) or secondary (electricity) energy sources and others. However, ownership is illustrated here for user reference when applying the ISDMF:

Table 2.2.2.2: Property Ownership and Outcomes (derived from Ostrom 1990)

	Property rights	Common ownership or lack of property rights
Bad outcome/tragedy	Tragedy of the anticommons	**Tragedy of the commons**
Good outcome/cornucopia	normal case	Inverse commons

Game theory is an extensive science subject to a great number of factors and assumptions. Throughout this subsection, basic two player game theories are reviewed to provide the ISDMF user with analysis 'starting points' to contemplate and assess how individual motivations and behaviors come together in competition to optimize sustainable decision-making. This investigation offers a basic understanding of the concepts of cooperation, defection, central authority involvement, information availability, disclosure, and communication to assess the Competition between Players.

As a final element in the Define Current State step of the Framework, this review of prior work now turns to the concept of collective action termed "Assess Cooperative Interaction Level and Potential toward Local, Sustainable Solutions" in the ISDMF.

2.2.3. Current State and Collective Action - Common Pool Resource / Social Ecological Systems

The final step in the Define Current State element of the ISDMF is to realize prior works that help a user evaluate and understand levels of cooperative interaction between players within their operating environments. In previous sections of the Literature Review, sequential concepts were presented to assess individual player motivation by applying the Five Forces of Competition by Porter, then competitive two player game theory interactions of participants in the resource chain. With individual player and game relationship defined, Current State development also requires consideration of cooperative, open action between the players. Sustainable decision-making is dependent on these factors, to a point that a third and emerging perspective of player Cooperation is worthy of further development.

Perhaps the most prolific and empirically supported expert in the study of 'commons' management is the late Elinor Ostrom. Over her career spanning nearly five decades, Ostrom synthesized and contributed a vast collection of socio-economic philosophies and empirical studies surrounding shared resources or ‘commons’, and placed great emphasis on scope definition and the importance of local player participation. For this Framework, three key elements of her work are presented to close the Current State analysis of sustainable management as a starting point: (1) Localized consideration of the sustainable actions for the resource, (2) Clear identification of internal and external forces that affect outcomes, and (3) Cooperative, honest participation by all players. The following sections develop each of these three points.

Ostrom invested a large portion of her career on the effect of community size and positioning on the ability to converge on sustainable actions. She demonstrates through her research that localized, committed player involvement is the most critical factor to install a sustainable resource management scheme. (Ostrom 1990) As was reviewed in the Introduction, the World Commission on Environment and Development (OCED) released Our Common Future in 1987, also known as the Brundtland Report, targeted toward resource sustainability. A widely accepted philosophy from those and other efforts is that all citizens contribute to a sustainable Quality of Life, and supporting research went further to state that “the traditional forms of national sovereignty are increasingly challenged by the realities of ecological and economic dependence.” (WECD 1987) However, decades of investigation demonstrate

that while a common vision of a sustainable future is embraced, geographic uniqueness and market conditions drive tailored solutions across the globe to varied degrees of success.

Localized Consideration

Most contemporary resource sustainability strategies are established by applying localized, top down approaches as witnessed through federal and state regulatory efforts or companywide goals. Earlier in the Literature Review of framework types, this concept was termed "Quantitative Models and Goal Setting" designed to be specific to unique settings. These approaches are valuable and effective at driving holistic incorporation of relevant players in a specific setting.

Ostrom focused much of her research toward the advantages and disadvantages of this approach, and presented research and insight to further confirm appropriateness of localized approaches with regard to depletable resources across multiple industries. Her epiphany, and a basis for her a Nobel Prize in 2009, is that localized community driven management of resources is best directed by those immediately affected through tailored, local policies and active player participation. She presents these findings through empirical analysis and innovative comparative methods to support her conclusion. The ISDMF integrates her findings that resource management best occurs under localized structures that fully incorporate affected participants.

This realization is critical, as often distant governance is established to provide equity to a given group of communities in a geographic scope (a U.S. state for example). However, with her Common Pool Resource (CPR) and Social Ecological Systems (SES) frameworks, Ostrom highlights the pitfalls of widespread governance when compared to focused, localized resource management. Her conclusion is that distant management often does not fully comprehend localized sustainability challenges, are not as immediately affected by policy outcomes, and can implement policy measures that do not benefit local sustainable resource decisions. (Ostrom 1990) This is exemplified at the state level via legislation that often benefits state markets in terms of profit or goodwill, but can overlook more localized approaches better suited to ensure resource sustainability for a specific community within a state.

As Ostrom points out, "Scientific knowledge is needed to enhance efforts to sustain SESs, but the ecological and social sciences have developed independently and do not combine easily. (Norgaard 2008) Furthermore, scholars have tended to develop simple theoretical models to analyze aspects of resource problems and to prescribe universal solutions. For example, theoretical predictions of the destruction of natural resources due to the lack of recognized property systems have led to one-size-fits-all recommendations to impose particular policy solutions that frequently fail." (National Research Council 2002)

Ostrom and others reconcile this challenge by crafting an economic theory that facilitates the consideration of scope. Her SES model presented below adds to the ISDMF by considering factors that can affect the two player game, yet may not be considered in the initial assessments under the preceding framework components of Porter's Five Forces (individual motivations) or competitive game theory. She presents these complex relationships and method to differentiate framework categorization of resource and player identification in the following diagram (Ostrom 2009a, p. 420):

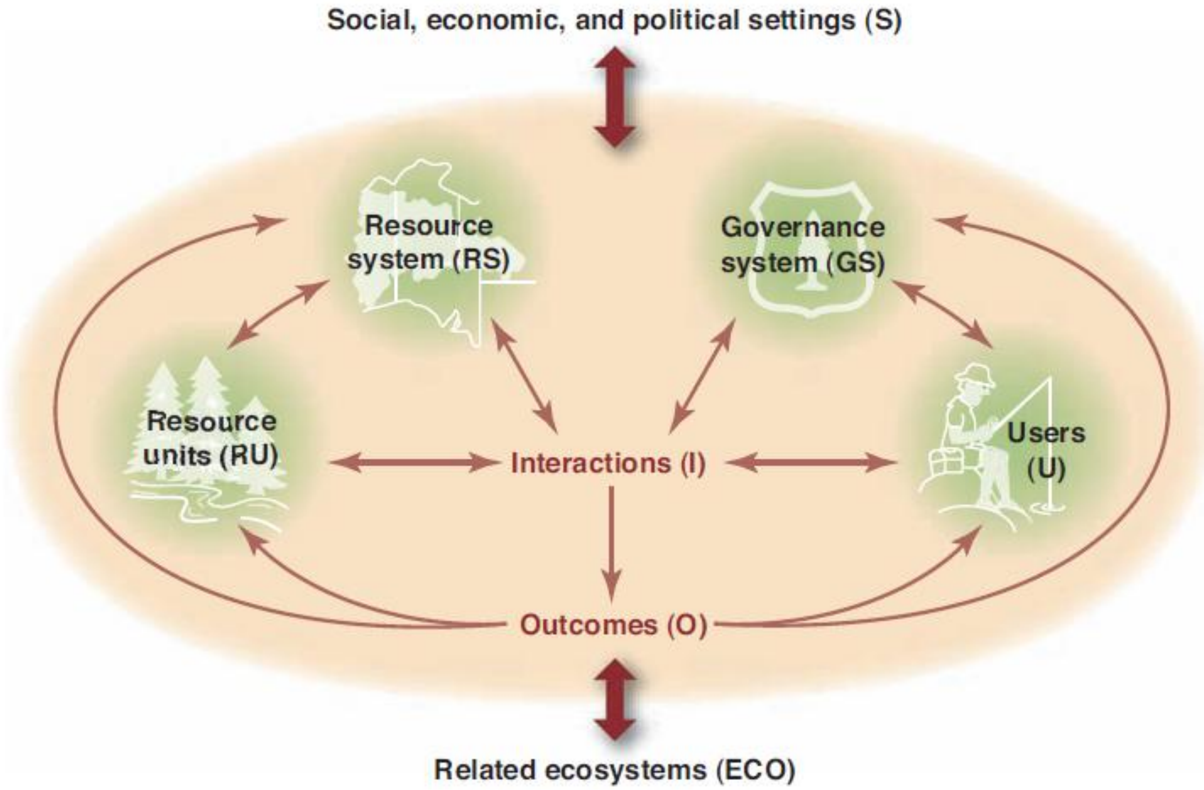


Figure 2.2.3.1: Core subsystems in a framework for analyzing social-ecological systems (Ostrom 2009a)

Ostroms macroscopic perspective helps better visualize the segregation of local and distant scope of influence, which is critical to understand formulation of a sustainable solution using the ISDMF. These considerations can affect the development of all Framework elements from visioning through performance measurement once implemented.

Identification of Internal and External Forces

In tandem with the need to understand local versus distant factors in sustainability solutions, an approachable and actionable framework must consider the importance of factors internal to the proposed solution versus factors that are external. This differentiation may be subtle, but is fundamental to support the ISDMF application to appropriately categorize and assess factors that influence sustainability of a given solution.

Internal factors are those found immediately within the groups of involved players. While these factors may not be controlled by the players at any given moment, they can be adjusted by the players when a collective sustainability strategy is adopted. Communication, trust, available funding, and local policies are examples of internal factors. External factors differ in that they are elements outside the scope of control or influence of the players in the game. Some examples of these factors include quantity and timing of rainfall, temperature, availability of sunlight, or the price of crude oil.

Ostrom's Governing the Commons volume presents the basic framework for sustainability consideration of internal and external factors. As illstrated in the flow of her work, Ostrom implicitly applies both individual assessment and a basic yet applicable form of game theory. With those two frameworks already considered as an integrated economic framework, scoping activities can be applied following Ostrom's Common Pool Resources framework which is reproduced below:

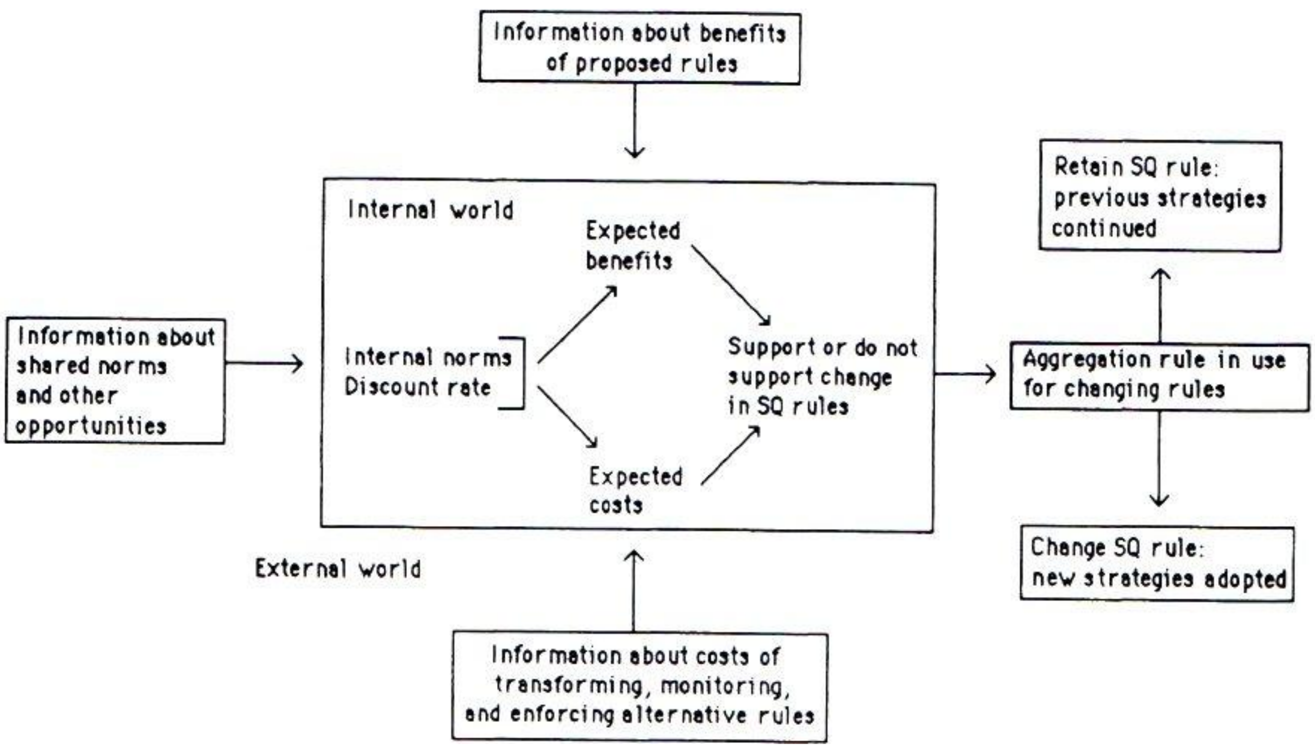


Figure 2.2.3.2: Summary of variables affecting institutional choice (Ostrom 1990, p.193)

This visualization is particularly expansive of the two player game theories, as Ostrom creates a delineation between Internal World and External Worlds that govern the competitive game. The implicit enhancement to the individual (Porter's) and collective (Competitive environment) elements of this economic assessment is that specific, external forces outside the affected parties may have dramatic influence on sustainability outcomes. Equally important, inability to effectively control internal forces can restrict any effort to implement sustainability strategies.

During her Nobel acceptance speech in December of 2009, Dr. Ostrom presented an expanded and more detailed series of views of internal and external factors. In "The internal structure of an action situation" slide, Ostrom summarizes key elements of the internal decision making process:

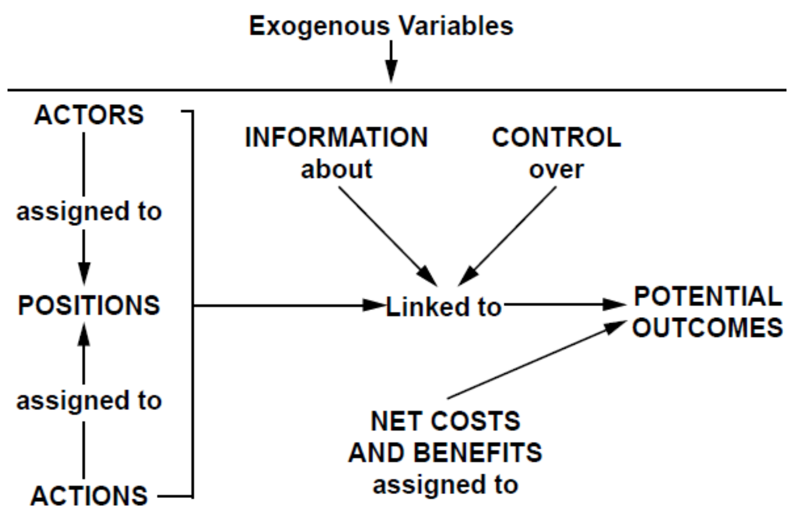


Figure 2.2.3.3: The internal structure of an action situation (Ostrom 2009)

As demonstrated above, players and their respective actions arrive at current state positions to begin strategy development. From there, additional information regarding a given situation is incorporated with existing information, and the level of player control may have over the 'potential outcomes' is considered. Once those outcomes are available, information regarding the 'net costs and

benefits' are evaluated toward outcomes, and an optimal strategy can be determined. Exogenous Variables are indicated as outside the scope of internal influence to reflect that they may or may not be known, and subsequently they are completely outside the control of the game players. Ostrom clarifies that this approach is general, and can apply across such diverse games as city council legislative decisions to innocuous card games.

Equally important is transparency of external or exogenous variables. A proposed sustainability solution is only valuable if it can be applied and provides desired outcomes. If external factors beyond the scope of control are not understood and create uncontrollable results, sustainability actions will not be achieved. To add greater resolution to the types of forces that create external, uncontrolled response in a given system, Ostrom also presented an overview of her method to categorize the types of exogenous factors that can affect sustainability outcomes:

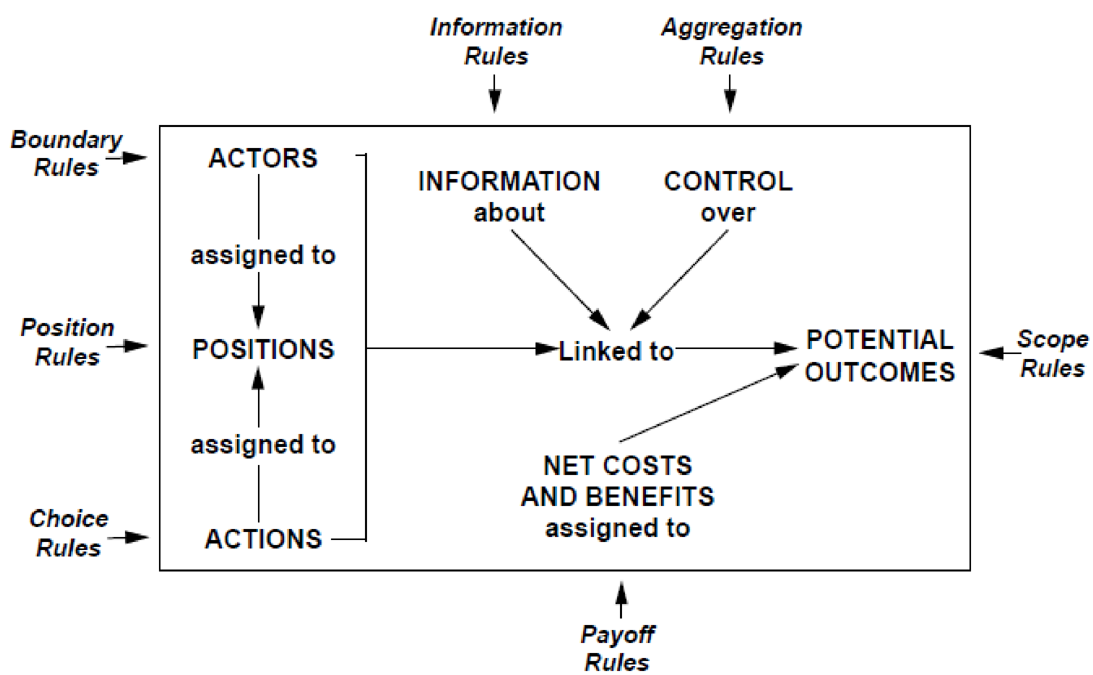


Figure 2.2.3.4: Rules as exogenous variables directly affecting the elements of an action situation (Ostrom 2009)

As shown in the above diagram, the general exogenous categories can be further be separated into specific types of factors that affect the internal processes of resource sustainability outcomes. Ostrom, and other contributors, offer the general concepts of exogenous variables directly related to each internal category of the strategy development process (Ostrom 2009a):

- Boundary rules to Actors – Actors are determined by the boundaries established for the socio-economic system being considered; these could be physical, geographic location or by grouping rules established.
- Position rules to Internal Positions – Position rules are created by constraints placed on the system, such as availability of sunlight, oil, or some other resource or relationship.
- Choice rules to Actions – To quote Ostrom from her Nobel presentation: "How do people know what they can do, and NOT do?" (Ostrom 2009a)
- Information rules to Internal Information – Internal and External rules that affect how much information is available.
- Aggregation rules to Control – How much is known about control options available, and how is that disparate collection of control units assembled into a mass or whole?
- Scope rules to Potential Outcomes – What outcomes are actually feasible for the given scope of influence or the problem itself?
- Payoff rules to Net Costs and Benefits – How can costs and benefits actually be realized? For example, does the environment and outcome dictate that initial investment with gradual payback occur, or are small investments made over time for a large return at the completion of the strategic outcome?

Cooperative Participation and Trust in Sustainable Assessment – The Free Rider Concept

Three risks to sustainable decision-making exist related to the application of an approachable, actionable, and adoptable sustainability framework. A community will likely be challenged by players

that work to gain advantage over others, particularly do not participate equally with the common goals and commitments of the larger society. The effectiveness of any framework is then dependent on the collective participation of all rational players, and they must trust that their involvement is equitable and promotes improved Quality of Life both in the short and long run. Ostrom summarizes the importance that trust, cooperation, and holistic benefits have in sustainable solutions in the following figure 2.2.3.5:

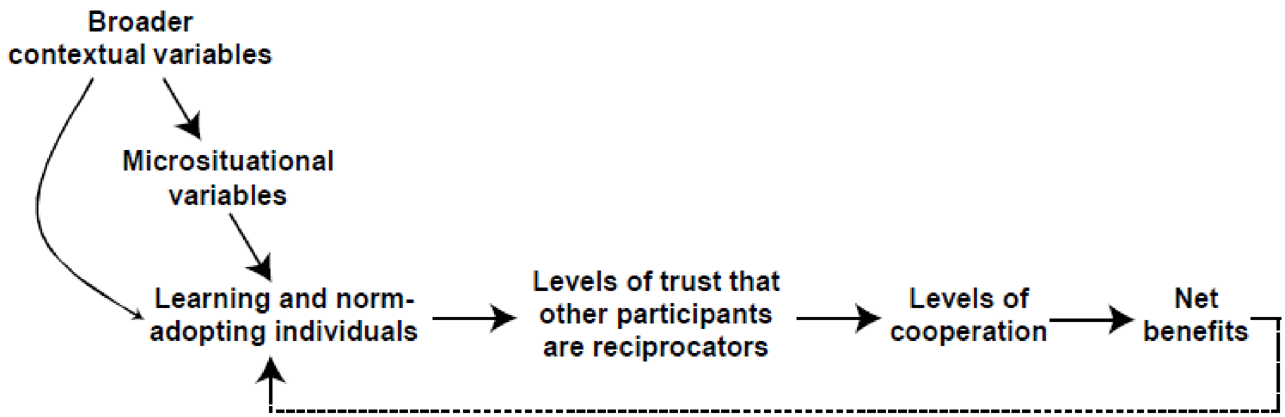


Figure 2.2.3.5: Micro situational and broader context of social dilemmas affects levels of trust and cooperation (Ostrom 2009)

Across several of her works, Ostrom also develops and summarizes three key concepts that are considered in the development of the Integrated Sustainability Decision-Making Framework: (1) Free-riders, (2) Theory of the Firm, and (3) Theory of the State. These topics are developed in the following subsections.

Free Riders

Merriam Webster defines a Free Ride as “a benefit obtained at another's expense or without the usual cost or effort.” (Merriam 2014) When dealing with resource sustainability, free riders affect a prescribed sustainability solution can deliver by threatening confidence and integrity of a strategy. Ostrom further supports this definition by describing that “At the heart of each of these models is the

free-rider problem. Whenever one person cannot be excluded from the benefits that the others provide, each person is motivated not to contribute to the joint effort, but to free-ride on the efforts of others. If all participants choose to free–ride, the collective benefit will not be produced. The temptation to free-ride, however, may dominate the decision process, and thus all will end up where no one wanted to be." (Ostrom 1990, p. 6)

Others support Ostroms theory that Free Riders limit or erode Community prosperity. Leading American economist Mancur Lloyd Olson, Jr., in his 1965 publication 'The Logic of Collective Action, Public Goods, and the Theory of Groups', presented a central theory that rational individuals will only work toward the benefit of their respective communities if incentivized. This observation becomes concerning when rational players seek to maximize investment returns at the expense of the others in the collective group. Olson summarizes the concept in his widely publicized and quoted statement: "unless the number of individuals is quite small, or unless there is coercion of some other special device to make individuals act in their common interest, rational, self-interested individuals will not act to achieve their common or group interests." (Olson 1965, p. 2)

An example of this concept is illustrated though the recent attempts to levy taxes on carbon production, also known as Cap and Trade. Fundamentally, the basis of this tax proposal resided in directing the 'total' or life cycle cost of fossil fuel combustion to the entity generating the emissions. In a sense, the true cost to 'Quality of Life' of the Community is not currently borne by the entity benefitting from the relationship but instead is absorbed, quite literally, by the entire affected Community. In these scenarios, the delivery entity then becomes a free-rider, and the collective benefit to the larger community is reduced by exploitive action of a single player. A result of this scenario is then dissolution of sustainability action through moral hazard and confidence erosion.

Willingness to Participate: The Influence of Player Trust

Level of trust plays an important role when considering both individual and competitive behaviors. Participant choice to embrace a more sustainable decision can be greatly affected by the

promoting entity. If doubt surrounding a sustainable strategy is generated by lack of trust in the originating entity, even worthy solutions will be met with skepticism and likely will not be adopted.

This risk has been identified by many researchers, but perhaps one of the more comprehensive and current assessments of this issue in the United States is quantified by researchers at the University of Texas at Austin with their annual Energy Poll. (UT 2013) For the U.S. population, data suggests that citizens have low levels of trust in most resource related entities. Figure 2.2.3.6 is a reproduction of their 2013 comparative results of confidence in energy solutions by entity or individual:

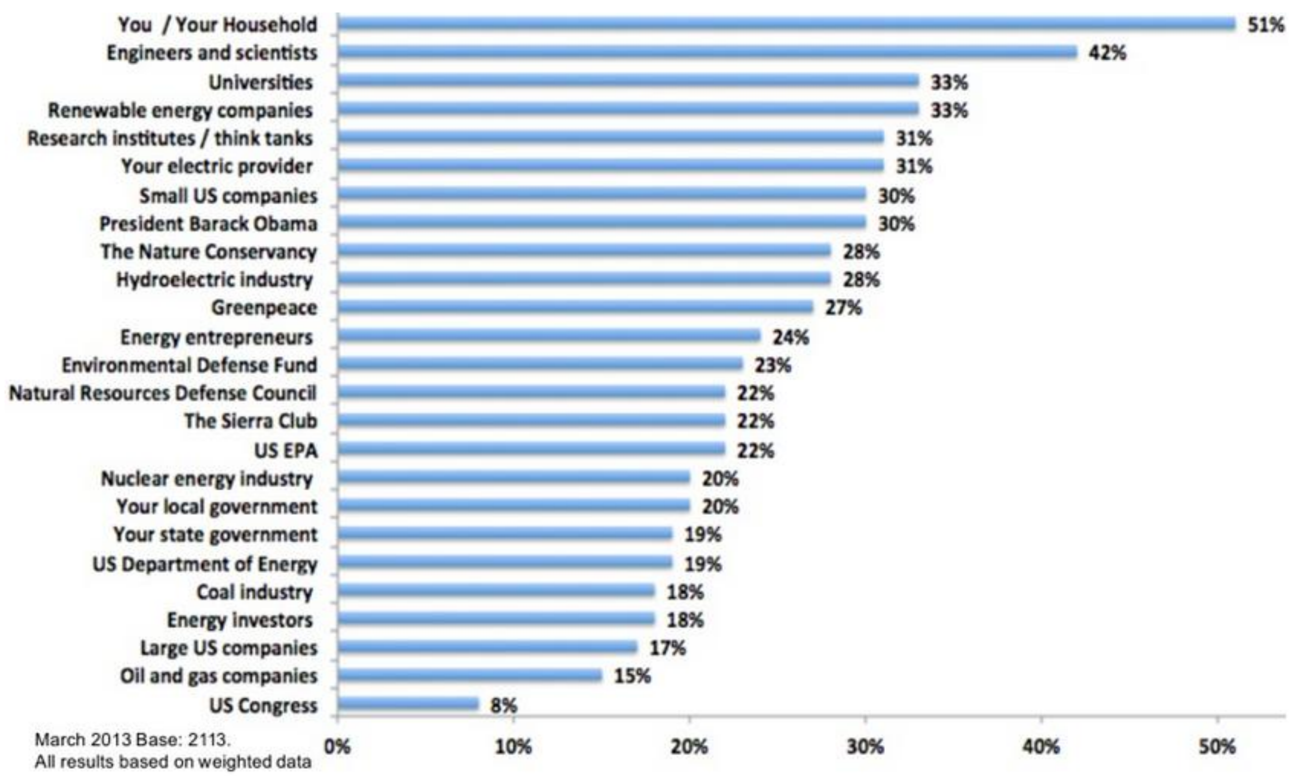


Figure 2.2.3.6: University of Texas energy Poll: Are you satisfied with the job that each is doing to address the energy issues most important to you? (UT 2013)

This information is included as prior work and to arm the user with a readiness for the potential risk of failed sustainability strategies merely because of the strategy communicating entity (source). Level of trust is a core factor affecting adoption (Rogers 2003), and is presented here as a behavioral

influence for sustainability strategy consideration. Further discussion of adoption can be found in section 2.4.

Theory of the Firm

Theory of the Firm enters into sustainability decision-making when an individual within the Community seizes an opportunity to become an entrepreneur, and negotiates contracts to affect the behavior of other participants within the Community. This theory is included as support for ISDMF application, and can raise user awareness regarding how players may act as a coordinated group rather than individually. Ostrom describes their relationships and motivations in the following way:

> "The entrepreneur is highly motivated to organize the activity in a manner as efficient as possible. The entrepreneur attempts to craft contracts with agents [individuals] that will induce them to act so as to increase the returns to the entrepreneur, and the entrepreneur monitors the agents' performances. The entrepreneur can terminate the contract of an agent who does not perform to the satisfaction of the entrepreneur. Because agents freely decide whether or not to accept the terms of the entrepreneur's contract the organization is considered private, voluntary, and at least by some individuals, nonexploitative. If there are large residuals to be obtained, however, it is the entrepreneur, not the agents, who receives them." (Ostrom 1990, p. 40)

This situation as related to two player game theory can be represented through the case of regulated, private electricity utilities. In essence, contracts are established for a resource at given rates as negotiated by the utility to ensure repayment of all infrastructure and operational costs to deliver the commodity (electricity in this example) to the agents with acceptable rates of return to the utility (entrepreneur). Since the utility is a natural, fixed monopoly, it exercises a broad level of control over agents and can affect optimal sustainable outcomes. The utility will, as with any entrepreneurial arrangement, work to obtain maximum profit margin as Ostrom states in the preceding passage.

Theory of the State

The final cooperative concept considered in the ISDMF is the Theory of the State. Here, a structure very similar to the Theory of the Firm is installed but the entrepreneur is replaced by a ruler or governing body intent on acquiring residual benefits. This management style does contrast the Theory of the Firm as agents are reclassified as 'subjects'. In comparison to Theory of the Firm, relationships between players are not considered voluntary but rather forced with extraction of collective residuals taking the form of taxes, labor, actual monetary gain, or other forms of resources. Additionally, rulers can instill fear in their subjects by threatening 'severe sanctions if they do not provide the resources'. (Ostrom 1990, p. 41)

An example of this theory as applied to sustainability can be observed in the sale of gasoline in the United States. To use the resource, 'subjects' are required to accurately report and pay taxes to the 'ruler' to acquire and distribute the resource. If these taxes are not paid, the 'ruler' is empowered to penalize nonconformists monetarily and criminally. Trust in sustainable solutions would then be jeopardized if subjects believe the taxes to be unjustified, and use of a resource to generate community prosperity could become inadvertently restrained. As an example, over the past decade the U.S. witnessed a nearly 10% unit federal tax reduction in gasoline to combat increasing raw material costs, economic conditions, and to promote resource use as shown in figure 2.2.3.6 below:

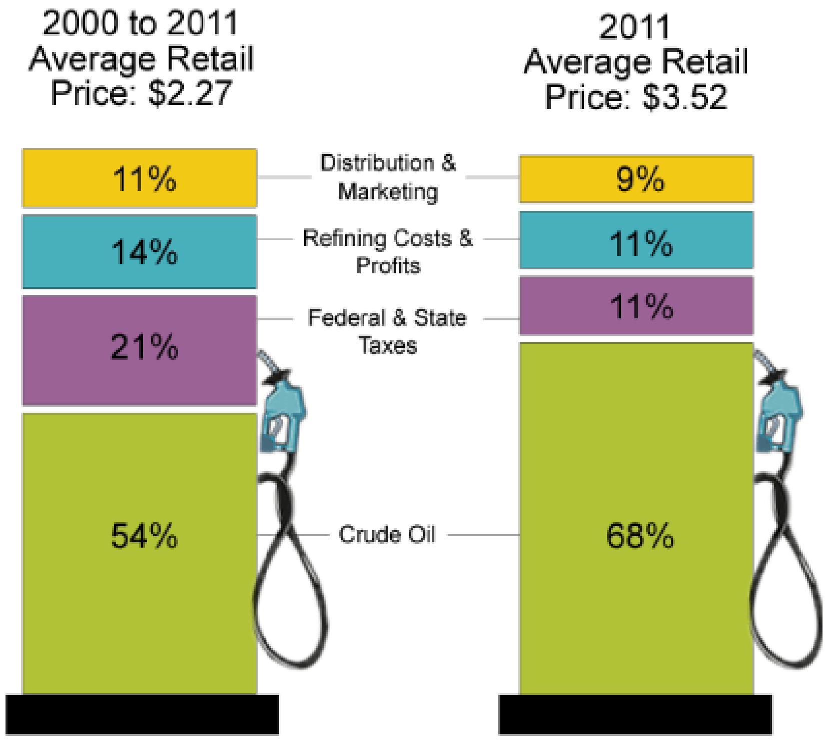


Figure 2.2.3.6: What do we pay for in a gallon of Regular Grade gasoline? (EIA 2012)

2.2.4. Current State and Collective Action Summary Concepts

As an overview of section 2.2, Elinor Ostrom presented a summary of design principles or 'Rules of Thumb' when operating an effective Common Pool Resource regime. She arrived at these principles by observing successful decision-making examples and comparing them to failed efforts. Threats presented to sustainable strategies can be minimized through use of Ostroms guidelines to establish effective resource distribution and management for specific community applications. These concepts are summarized in her paramount work Governing the Commons and reproduced below as a nested 'check list' for interested users to apply at the Current State ISDMF process step:

Table 2.2.4.1: Design principles illustrated by long-enduring Common Pool Resource (CPR) Institutions (Ostrom 1990, p. 90)

1. Clearly defined boundaries
   Individuals or households who have rights to withdraw resource units from the CPR must be clearly defined, as must the boundaries of the CPR itself.
2. Congruence between appropriation and provision rules and local conditions
   Appropriation rules restricting time, place, technology, and/or quantity of resource units are related to local conditions and to provision rules requiring labor, material, and/or money.
3. Collective-choice arrangements
   Most individuals affected by the operational rules can participate in modifying the operational rules.
4. Monitoring
   Monitors, who actively audit CPR conditions and appropriator behavior, are accountable to the appropriators or are the appropriators.
5. Graduated sanctions
   Appropriators who violate operational rules are likely to be assessed graduated sanctions (depending on the seriousness and context of the offense) by other appropriators, by officials accountable to these appropriators, or by both.
6. Conflict-resolution mechanisms
   Appropriators and their officials have rapid access to low-cost local arenas to resolve conflicts among appropriators or between appropriators and officials.
7. Minimal recognition of rights to organize
   The rights of appropriators to devise their own institutions are not challenged by external governmental authorities.

For CPRs that are parts of larger systems:

8. Nested enterprises
   Appropriation, provision, monitoring, enforcement, conflict resolution, and governance activities are organized in multiple layers of nested enterprises.

This concludes the economic assessment or Current State phase of the ISDMF. In this section, strategic and economic theories are reviewed as fundamentals of the ISDMF as an integrated toolset engineered to effectively assess individual player positioning, general game theory, and cooperation characteristics for decision-making. With these ISDMF steps complete, the process advances to next remind a user to considerimplementation impacts of a strategy based on observed, standard player

behaviors. This is the science of Archetypes, which are briefly summarized for use with the ISDMF as a base toolset, and presented in section 2.3

2.3. Sustainability Assessment and System Archetypes

Resource management is affected by many factors and sustainable decisions are not only determined by immediate, internal influences but also by external factors and policy structures. (Ostrom 1990) This interplay can culminate into a specific set of players and circumstances that converge on common behaviors among the players involved. Theorists have assessed these generic types of interactions across a wide range of industries and situations, and identified recurrent scenarios. These scenarios can be categorized and an accepted research of these assessed scenarios is Archetype theory.

Dr. Peter Senge invested a large part of his career to organizational and management study, and offers a comprehensive assessment of Archetypes is his 1990 work The Fifth Discipline: The Art and Practice of The Learning Organization. The Senge work, in particular his 1990 publication, develops the concept of the "Learning Organization" that heralded widespread recognition of his concepts. "The Journal of Business Strategy (September/October 1999) named Senge one of the 24 people who has had the greatest influence on business strategy over the last 100 years. The Financial Times (2000) named him one of the world's top management gurus, and Business Week (October 2001) rated Senge one of the top 10 management gurus." (MIT 2014) His contributions are certainly worthy of consideration in a sustainability process.

Senge's work on Archetypes is presented in this section as a proactive means of addressing potential player conflicts within resource 'games' prior to sustainability strategy implementation. He offers ten Archetypes that analyze recurrent behavioral and organizational systems assessments, and explains that "One of the most important, and potentially most empowering, insights to come from the young field of systems thinking is that certain patterns of structure recur again and again. These 'system archetypes' or 'generic structures' embody the key to learning to see structures' in our personal and organizational lives. The system archetypes - of which there are only a relatively small number - suggest that not all management problems are unique, something that experienced managers know intuitively."

(Senge 1990, p. 94) He further explains that system archetypes "reveal an elegant simplicity underlying the complexity of management issues. As we learn to recognize more and more of these archetypes, it becomes possible to see more and more places where there is leverage in facing difficult challenges, *and* to explain these opportunities to others." (Senge 1990, p. 94) Each identified Archetype offers value, and as introduction and Literature Review of the concept this work briefly mentions three of the most relevant Archetypes for sustainable resource management application: Accidental Adversaries, Escalation and Tragedy of the Commons.

The Accidental Adversaries Archetype begins with the best intentions of a 'win-win' strategy for both players, and can grow into a destructive scenario unintentionally. The base Archetype can occur when parties enter into an arrangement where each benefits from the collective relationship over individual operation by maximizing strengths while minimizing weaknesses. The 'accident' occurs when one player takes an action that the other perceives as threatening or damaging to their position and outside of the agreement. This inadvertently creates an adversarial condition by raising suspicion and distrust with the 'offended' party, who then takes a defensive position. These actions by each player eventually can destroy any initial synergies and lead to a downward spiral of performance. The complete Archetype assessment is available in Appendix B. (Braun 2002)

Similar to Accidental Adversaries, the Escalation Archetype provides decision-makers with a template of generic organizational challenges and solution options when participants perceive the actions of other players as threats and react aggressively to reestablish advantage. This Archetype can be destructive to the entire system, as Dr. Senge points out "Often each side sees its own aggressive behavior as a defensive response to the other's aggression; but each side acting 'in defense' results in a buildup that goes far beyond either side's desires." (Senge 1990, p. 384) A more comprehensive summary, description, behavior and proactive adjustment for the Escalation Archetype is available in Appendix B reproduced from Braun (2002) based on Senge's work.

The third resource sustainability Archetype for this brief introduction to the theory is the 'Tragedy of the Commons', a principle developed earlier in this chapter based on the works of Lloyd, Garrett, and Ostrom. Senge describes that the Tragedy of the Commons scenario occurs when

"Individuals use a commonly available but limited resource solely on the basis of individual need. As first they are rewarded for using it; eventually, they get diminishing returns, which causes them to intensify their efforts. Eventually, the resource is either significantly depleted, eroded, or entirely used up." (Senge 1990, p. 387)

Many resource-based competitive environments arrive at these critical states of scarcity risk both directly and indirectly. Direct cases include many examples ranging from deforestation, over consumption of fisheries, water availability for agriculture, and arid conditions resulting from overgrazing of livestock. Other more indirect examples include air quality, energy availability, and transportation infrastructure.

Fortunately, resource transportation helps alleviate resource scarcity risk through movement of resources from a non-distressed community to a distressed one. However, the efficiency of resource delivery drops with increased movement requirements. As with the Escalation Archetype above, a more detailed overview of the Tragedy of the Commons is reproduced from Braun (2002) in Appendix B.

Perhaps the most difficult challenge for an ISDMF user is to determine the most appropriate Archetype to apply. A valuable template to ascertain a given Archetype strategy was developed by Michael Goodman and Art Kliener in 1993, and subsequently republished in Senge's Fifth Discipline Fieldbook in 1994. The Connections Between the Archetypes figure 2.2.4.2 reproduced below (Braun 2002) is a 'decision tree' to assist user archetype selection for a given sustainability strategy. The following Archetype selection template affords the reader a starting point to proactively address resource management challenges:

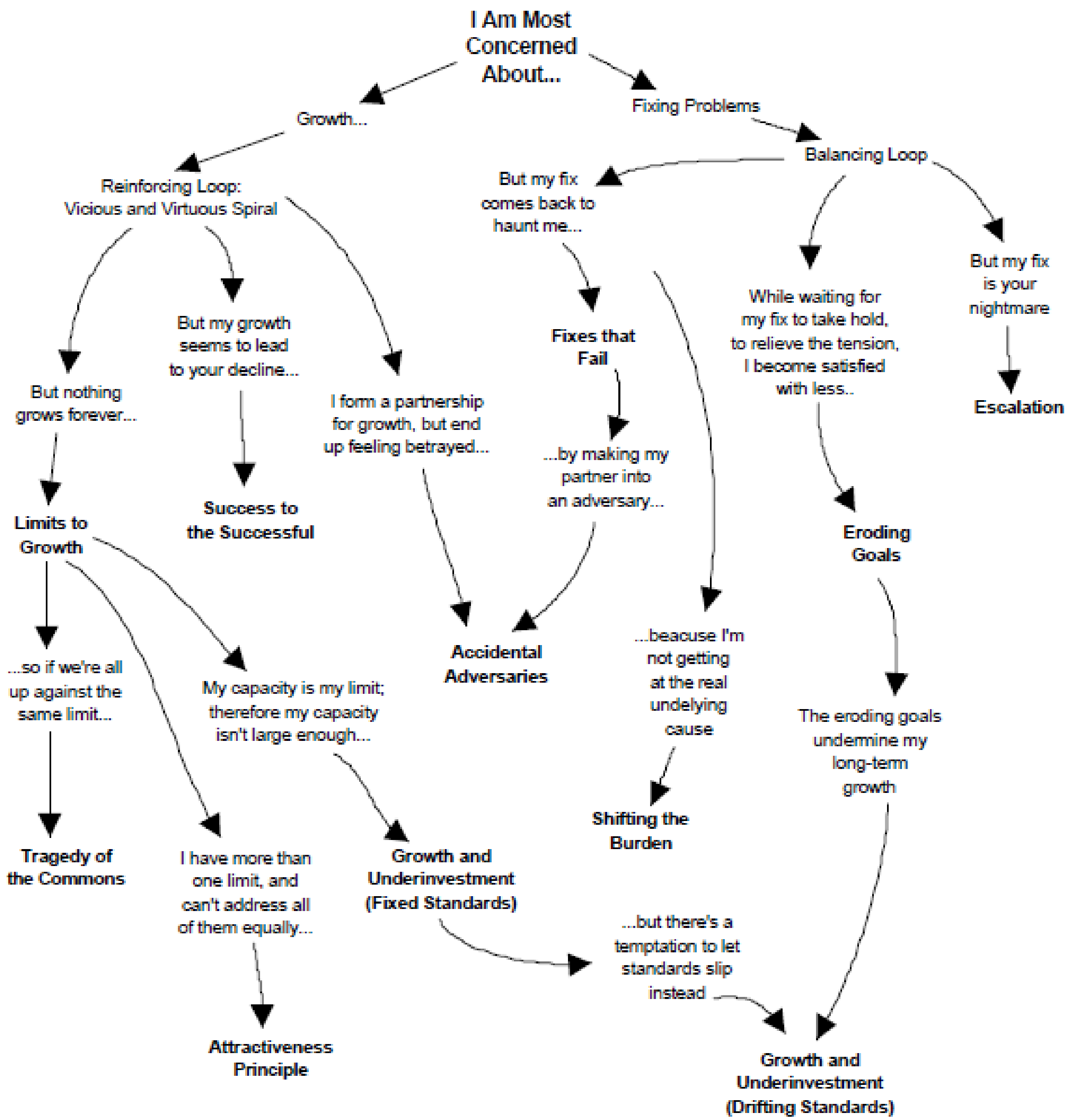


Figure 2.2.4.2: Connections Between the Archetypes (Braun 2002, p. 24)

This concludes the brief introductory overview of Archetype applications for proactive sustainability strategy development. These empirical systems frameworks allow a user to more

effectively address localized resource sustainability challenges resulting from system dynamics, participant behavior, and initial player positioning. As was mentioned, the objective of Archetype incorporation within the ISDMF is to remind users to assess current and projected game player behavior based on individual, collective, and finally internal and external considerations.

2.4. Corrective Action Strategies – Technology and Diffusion of Innovation

must be effectively developed to ensure success, and perhaps the most challenging requirement of a successful Sustainability strategy is sufficient community adoption. The ISDMF separates this science into a combined component that simultaneously considers technology and diffusion of innovation / adoption factors. Within the ISDMF, this step is comprehensively grouped into the Corrective Action Strategy component. Once the aforementioned steps are completed, ISDMF users then move to assess technology availability, development options, and respective adoption based on the prescribed process and check list.

A core contributor to adoption science or Diffusion of Innovation philosophy is Dr. Everett Rogers (1931-2004) who researched multiple technologies and adoption patterns to arrive at core diffusion theories. This introduction for Corrective Action Strategy summarizes the Rogers concepts as related to technological and behavioral solution options. Again, the objective throughout this review is to provide two principle considerations: The first is to support ISDMF selected contributors and summarize their relevant work; second is to provide the user with introductory reference points to fully develop sustainable resource management strategies.

Within the Framework and key to any innovation is technology. Rogers describes that an Innovation "is an idea, practice, or object perceived as new by an individual or other unit of adoption." (Rogers 2003, p. 36) He further explains that a Technology is "a design for instrumental action that reduces the uncertainty in the cause-effect relationships involved in achieving the desired outcome" which consists of two components: (1) Hardware, a material or physical object, and (2) Software, defined as the knowledge base for the tool. (Rogers 2003) As was mentioned in the Introduction, the focus of this work is the development and demonstration of the Integrated Sustainability Decision-

Making Framework and not an assessment of current state technologies. Case study assessment assumptions for technology performance are based on averages rather than any particular hardware.

Beyond technology, Rogers defines several other factors associated with diffusion assessment. Specifically, he outlines four basic components needed for diffusion to occur, which are summarized in the following statement:

> "The main elements in the diffusion of new ideas are: (1) an *innovation* (2) that is *communicated* through certain *channels* (3) *over time* (4) among the members of a *social system*." (Rogers 2003, p. 36)

This concise review of diffusion serves as an introduction for the ISDMF user, and highlights the four key elements of Rogers theory. Beyond his definition of Innovation listed above, Rogers also points out that for adoption to occur a market must have interaction among adopters which he calls Communication Channels. Mass media and personal relationships between participants are examples. Further, diffusion is a time based phenomena hence the need for '(3) Over Time'. Finally, the Social System "is a set of interrelated units that are engaged in joint problem solving to accomplish a common goal." (Rogers 2003, p. 38)

In addition to this set of four diffusion characteristics, Rogers theorizes that three primary types of innovation-decisions are made: (1) Optional (where participant decisions are independent of the group), (2) Collective (decisions made by consensus of the group), and (3) Authority based (where decisions are made by a few individuals with unique power, status, or expertise). As is the case with sustainability frameworks, a fourth innovation-decision type is labeled a Contingent innovation-decision, which is a combination of two or more of the primary types.

Rogers observed early in his research that innovation adoption often can be represented by a normal or Bell statistical curve, and if diffusion is charted across a total population the percent of adoption over time produces a curve similar to the letter 'S' in the alphabet (Rogers 2003). The concept of slow initial diffusion, steep increase with more rapid adoption, and exponential rate decay with late

adopters is termed the 'S' curve of innovation adoption or the Diffusion Process, reproduced as figure 1.3.3.4 (Rogers 2003, p. 11):

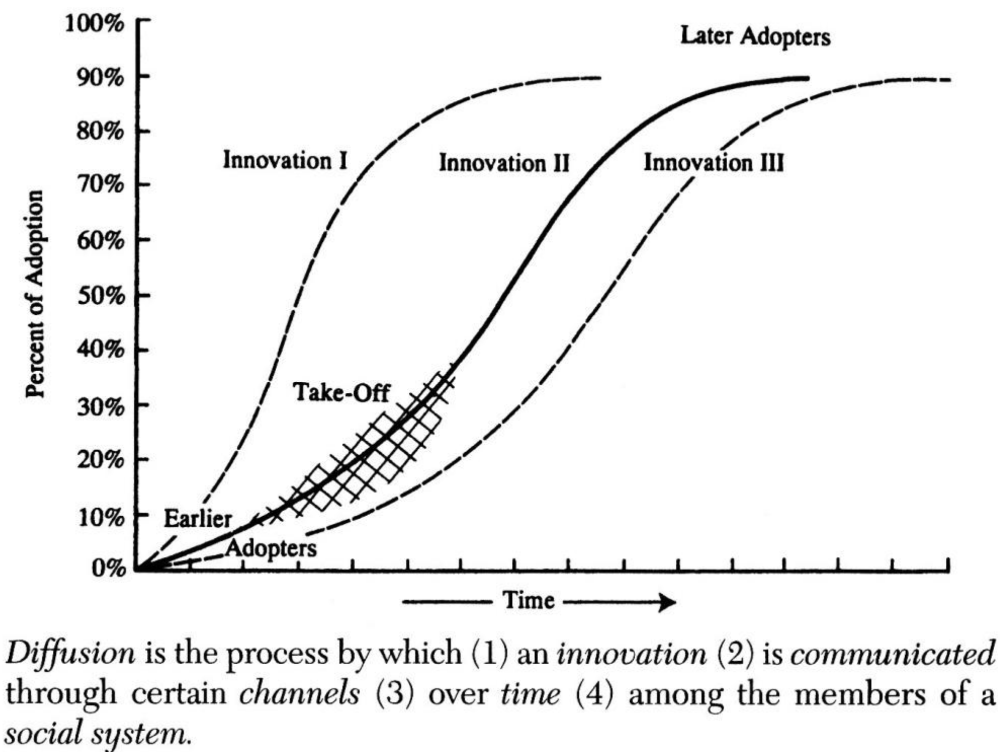
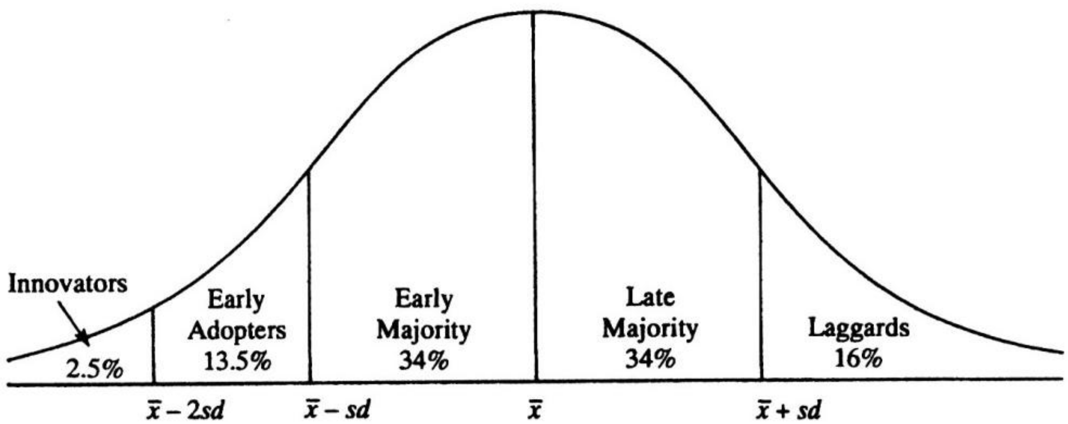


Figure 2.4.1: The Diffusion Process (Rogers 2003, p. 11)

The consistent "S" pattern among various innovations (Innovation I, II, and III) shows that common adoption profiles exist independent of a specific scenario. Rogers suggests that this shape is described by a normal distribution of adopters. These concepts have been demonstrated with statistical significance through his work, and represent trends for general behavioral and technological adoption.

Several statistical considerations must be exercised when viewing the categorization of innovation adopters. From Rogers publication Diffusion of Innovation, fifth edition, he explains various statistical studies demonstrate that "S-shaped adopter distributions very closely approach normality." (Rogers 2003, p. 280) Further, he postulated that 5 adopter categories exist: (1) Innovators, (2) Early Adopters, (3) Early Majority, (4) Late Majority, and (5) Laggards.

Rogers assumes that "a set of categories should be (1) *exhaustive*, including all units of study, (2) *mutually exclusive*, by excluding a unit of study that appears in one category from also appearing in any other category, and (3) derived from a single *classificatory principle*." (Rogers 2003, p. 280) The following reproduction of his work illustrates his assessment of segments and respective distribution, as figure 2.2.4.3 (Rogers, p. 281), which provides the ISDMF user with typical diffusion timeframes by adopter segment.



The innovativeness dimension, as measured by the time at which an individual adopts an innovation or innovations, is continuous. The innovativeness variable is partitioned into five adopter categories by laying off standard deviations (sd) from the average time of adoption ($\bar{x}$).

Figure 2.4.2: Adopter Categorization on the Basis of Innovativeness

As is implied by normal distribution of participant adoption types, pockets of individuals with similar beliefs and behaviors are identified within a community and adopt new sustainability methods at different times. (Rogers 2003)

In players identification to apply Rogers work, 'player' set differences exist and the concept of heterophily and homophily emerges as a factor to determine the speed at which a community will actually implement an accepted sustainability strategy. (Rogers 2003) From Rogers' Diffusion of Innovations, and as suggested by Allen in 1983: "It seems likely that individuals base their choice on

what they expect others to decide. Thus, the individual's effort to decide hinges upon 'watching the group' – the other members in the community of actual/potential subscribers – to discern what the group choice may be…. The outcome for the group then turns literally upon everybody watching while being watched." (Rogers 2003, p. 353) This concept evolves into not only working to obtain a best option based on the success of others, but also touches upon theories of peer pressure to conform and to raise perceived societal status. (Rogers 2003, p. 359-362)

From theories of homophily and heterophily (Rogers, 2003), individuals with similar beliefs and socio-economic positioning are likely to adopt behaviors of peers through social networking. Conversely, heterogeneous segments are slower to embrace changes observed from their socio-economic peers. This variation in demographics and beliefs of a given 'player' set can create barriers to effective sustainable strategy diffusion rates by limiting ability to achieve 'critical mass' of adoption.

Rogers defines that "the critical mass [of adoption] occurs at the point at which enough individuals in a system have adopted an innovation so that the innovation's further rate of adoption becomes self sustaining." (Rogers, p. 344) An illustration of this concept is presented below using the 'S' diagram concept, as figure 1.3.3.6, where the solid line is an 'average' adoption over time, and the dashed line reflects affect of reaching critical mass with more aggressive adoption rate:

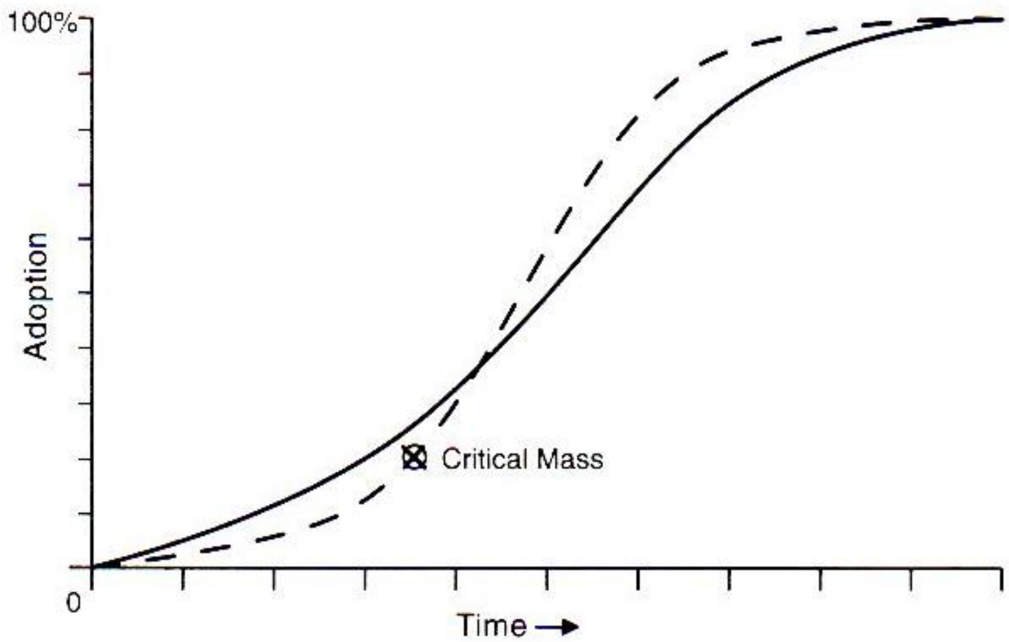


Figure 2.4.3: The Rate of Adoption for an Interactive Innovation, Showing the Critical Mass

The key implication of this theory is that for any sustainable strategy to be viable, once developed and launched, it must consider promotional strategies to most rapidly ascend to critical mass adoption levels. Under Critical Mass theory, player benefits are first derived by an Innovator and are then communicated by education and awareness campaigns by the individual or community. As more individuals adopt and gain ever increasing benefit from socialization of the solution, the community gains and the solution proliferates via communication and recognition of improved Quality of Life when applying the innovation. Some examples of this include public transportation (increased users boosts the number of routes and pickup schedules), the use of e-mail (the more people that have accounts, communication becomes more streamlined and can reach more audience which motivates individual adoption), and similar to e-mail the facsimile.

In summary, ISDMF users need consider the wide ranging effects adoption principles have on a resource sustainability strategy and continuously assess influence throughout the Framework application. The concepts of heterophily and homophily are touched upon in Everett's model reproduced

above, and are core to the basic understanding effective diffusion methods. It is important to recognize that the general grouping of different players and resultant rivalry will not likely be a simple endeavor in complex resource management systems. This topic of nested variance for a given defined player can be better understood through Rogers philosophies, and is important to consider as 'players' engaged in a two player game may actually represent wide ranges of participants under single groupings. This variation among a player segments can impact a technology or service innovation and sustainability strategy success.

2.5. Actively Assess and Refine Efforts to Promote Strategy

Active and appropriate measurement systems are fundamental for any process, and are extremely important when considering unsustainable resources trends. Once the involved players are identified and the resource under consideration is confirmed for framework application, key metrics that illustrate the sustainability performance can be determined. From there, measurement and monitoring systems must be implemented to understand how the individual and collective behaviors within the game affect sustainability objectives. This activity is case specific, and examples of metric development are demonstrated in the Introduction, Method, and Results sections of this work.

For user reference, the Establish Scope of Study section of the Framework provides an initial attempt at defining measurement points and metrics should be completed, and the result can be dynamic in that the number of metrics may change over time as sustainability actions are taken and Framework process and implementation is fully executed.

2.6. Literature Review Summary

This review of prior work and support materials provides comparative examples to demonstrate uniqueness of the ISDMF and established, supporting theories as starting points for process operation. Referenced supporting concepts are only an introduction to the extensive bodies of work available from this set of experts, and provide users with terminology to further develop the ISDMF concepts tailored for unique applications. Armed with ISDMF development from the Introduction and Supporting Theory

in the Literature Review, the next step is to prove ISDMF value through practical application. In the next section, Method, 'real world' Framework application is demonstrated.

Method

The ISDMF is a novel checklist for users to strategically assess decisions to accelerate convergence on more prosperous resource sustainability outcomes. Framework differentiation and definition were presented in sections 1 and 2, and this Section 3 is dedicated to testing the ISDMF in practice. The Method to confirm ISDMF usefulness is to apply it to the previously identified resource and test cases heuristically andarrive at resultant metrics and decision strategies based on public domain data available to all members of the resource chain.

This Methods section is structured based on the ISDMF application and presents key decision metrics for distinct regions of value and behavioral considerations of the electricity resource incorporating grid-tied residential PV generation for the target Communities. Three distinct types of metrics are proposed: (1) Individual motivation of players, (2) Cooperative Impacts, and (3) Adoption Levels and Rates. Each metric requires a structure for objective development, and their structures are presented starting with a metric description and importance, an evaluation of data elements required, respective heuristic data and explanation of assumptions surrounding each, and establishment of the resultant metric. In this 'virtual' application, key Framework questions are answered through the metrics, which are then consolidated to understand Community and Utility positioning strategies regarding incorporation and adoption.

3.1. Case Study Validation of Vision, Goals, and Boundary

Resource management principles and strategies can be viewed under a comprehensive Vision of sustainable action to positively affect current and future Quality of Life. As was defined in the Introduction, electricity is a core resource that indicates and affects Community prosperity. In this case study assessment, high level Goals are to (1) establish the current state assessment for each case study positioning and (2) recognize best practices and improvement opportunities to enhance resource sustainability. A clear decision-making opportunity is available to both players considered here, Community and Utility, as an emerging technology of residential grid-tied photovoltaic electricity generation can play a role in community prosperity advancement.

With high level Vision and Goals established, a brief restatement of boundaries is provided below to define data throughout the remainder of this section:

- Phoenix, Arizona - Considers city boundaries in Maricopa County, only serviced by Arizona Public Service.
- Portland, Oregon - Considers city boundaries in Multnomah County, only serviced by Portland General Electric.
- El Paso, Texas - Considers city boundaries in El Paso County, only serviced by El Paso Electric.

These details describe the Establish Scope of Study initial element of the Framework, with the only remaining step being metric refinement and assessment. The remainder of the ISDMF is applied in the following sections to present available electricity management metrics and respective supporting data.

3.2. Definition of Current State: Individual Behavioral Models

As presented in the Introduction, individual behavior is initially assessed under the ISDMF by applying Michael Porter's Five Forces framework for each player (Community and Utility in the residential, grid-tied PV case). These concepts and application were discussed throughout the Introduction and Literature Review. As prescribed, Community decision-making is considered first as an independent player for each test environment. Respective changes hinges on individual Community member investment in the game changing technology. With this in mind, the first metric for Framework application is an assessment of Net Present Value (NPV) of investment for a given Community member.

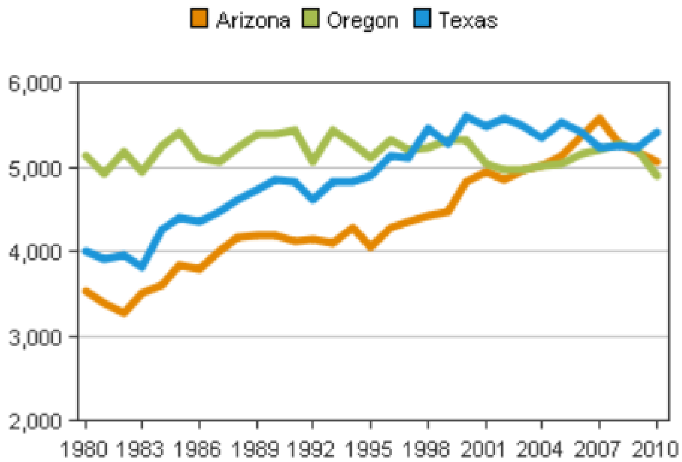
Many investment considerations affect the creation of an NPV model for a residential photovoltaic investor. As examples, electricity purchase from the incumbent Utility can be dynamic based on charge variation, and installation cost of alternatives is dependent on unique installers offering various and dynamic products and services. The following NPV models make assumptions and effort to address variability and provide projected investment returns or lossesfor Communities based on 'out of pocket' system installation price. Throughout the section, data sources and assumptions further explain the details surrounding metric presentation for comparison.

Community Individual Motivation

Community investment benefit from a residential grid-tied photovoltaic system is a major factor to determine the level of potential adoption of this technology. Financial impacts of equipment purchase and installation contribute to understanding adoption and subsequent resource sustainability. Historically, PV investment price points were too high to enable widespread adoption on a pure financial basis. But, economy of scale in manufacturing combined with efficiency in Balance of System (BOS) costs continue to bring price points closer to more realistic adoption potential.

To create a general financial model for the case studies, the following data elements and assumptions are required:

- <u>Identify average PV system generation required for each city and size system based on expected generation and consumption:</u> This metric is used as per capita electricity consumption for each test case. Test case electricity sustainability comparisons require that markets have similar Community member demand for objective comparison. From the Department of Energy, individuals in each community consume nearly equal amounts of electricity in the three case studies on a state basis:



State	State Annual per Capita Electricity Consumption (kWh)	Variance from Average (5133 kWh)
Arizona	5059.72	-1.4%
Oregon	4908.55	-4.4%
Texas	5431.47	5.8%

Figure 3.2.1: Residential Electricity Consumption Per Capita Compared to Other States (US DOE, 2013a)

- <u>Quantify residential PV system nameplate size for average residential PV application:</u> System size is governed by performance of the system in the given environment, largely based on solar insulation. Each identified test case has different performance due to solar access, and these results are provided on an annual kWh generation basis. For this study, the average size of system is determined to be 4.7kW based on the national average from 1998 to 2009, as published by the Berkley Laboratories (2009). Conservatively, based on trend and convergence of national data, a baseline of 4.7kW in El Paso will be used as a generation for all test cases.

  In this assessment, this reported average system size will be converted to kWh generation for the home by using the Department of Energy estimation tool called PVWatts, which is operated by the National Renewable Energy Laboratory (NREL). This tool is used to calculate expected solar system power output in terms of kWh, and is often incorporated into other industry assessment tools. The NREL PVWatts tool output is assumed a standard for estimating residential photovoltaic systam electricity generation. The assumptions used for the tool are reproduced below in figure 3.2.2.

Note: With PVWatts analysis, NREL recommends the use of the listed derate factors when calculating nameplate sizing to determine production. Use of these performance calculation tools can introduce an element of subjectivity, so an assumption for this study is that the NREL PVWatts system is accurate. In this research, PVWatts output is used for all locations to calculate system size based on generation capability. PVWatts assumptions caution that "energy production values in the table are estimated using coefficients relevant to crystalline silicon PV systems, assuming common silicon module designs." (NREL 2013b)

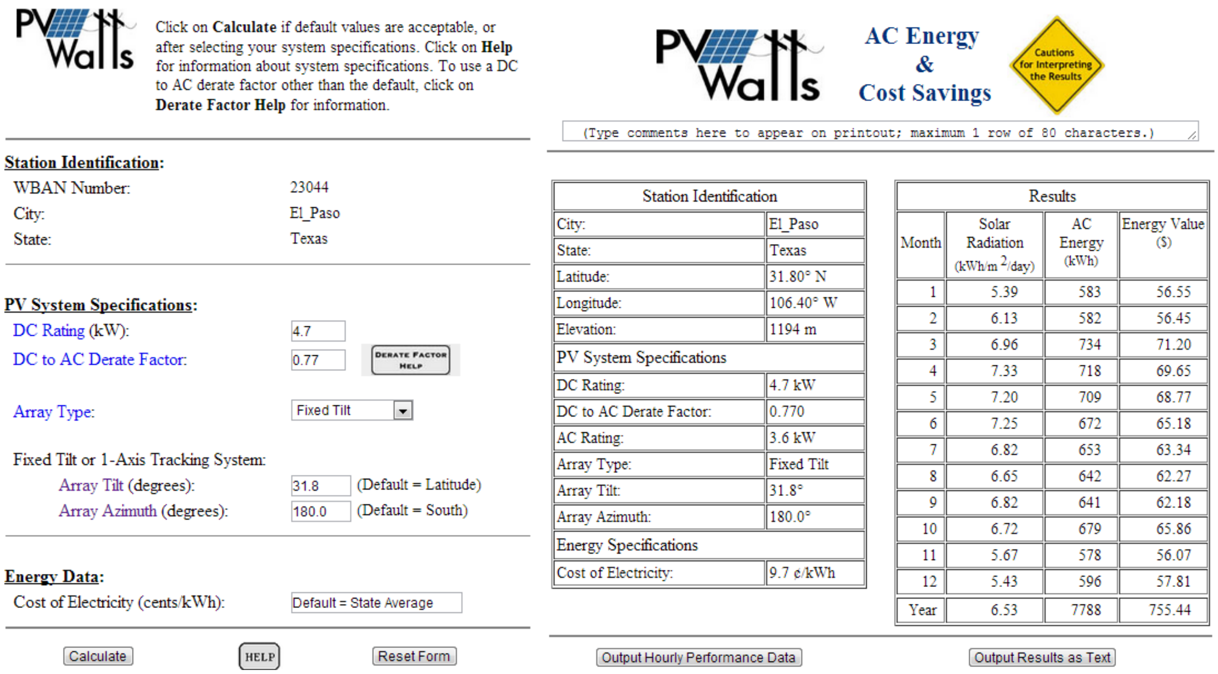
If the default overall DC to AC derate factor of 0.77 is not appropriate for your PV system, you may use this calculator to determine a new value by changing one or more of the component derate factors in the table and clicking the "Calculate Derate Factor" button. You may enter values within the ranges shown in the table. Values outside the ranges are reset to to the default values by the derate calculator. The new overall DC to AC derate factor may be hand entered, or copied and pasted, into the "DC to AC Derate Factor" field on the PV Systems Specifications section of the PVWATTS input form. Click on **HELP** below the table for information about DC to AC derate factors.

Calculator for Overall DC to AC Derate Factor

Component Derate Factors	Component Derate Values	Range of Acceptable Values
PV module nameplate DC rating	0.95	0.80 - 1.05
Inverter and Transformer	0.92	0.88 - 0.98
Mismatch	0.98	0.97 - 0.995
Diodes and connections	0.995	0.99 - 0.997
DC wiring	0.98	0.97 - 0.99
AC wiring	0.99	0.98 - 0.993
Soiling	0.95	0.30 - 0.995
System availability	0.98	0.00 - 0.995
Shading	1	0.00 - 1.00
Sun-tracking	1	0.95 - 1.00
Age	1	0.70 - 1.00
Overall DC to AC derate factor	**0.769**	

Figure 3.2.2: PVWatts Photovoltaic Calculation Derate Factors (NREL 2013a)

Based on these PVWatts assumptions, and an increasing and converging electricity demand (US DOE, 2013a) across the three case study entities, a baseline generation profile will be applied using El Paso as the reference for individual Community member financial assessment. Per PVWatts, a 4.7 kW fixed tilt photovoltaic system in El Paso, Texas can be expected to generate an average annual power output of 7,788 kWh as shown in the following reproductions of input and output screens in PVWatts:


PVWatts

Click on **Calculate** if default values are acceptable, or after selecting your system specifications. Click on **Help** for information about system specifications. To use a DC to AC derate factor other than the default, click on **Derate Factor Help** for information.

Station Identification:

WBAN Number:	23044
City:	El_Paso
State:	Texas

PV System Specifications:

DC Rating (kW):	4.7	
DC to AC Derate Factor:	0.77	DERATE FACTOR HELP
Array Type:	Fixed Tilt	
Fixed Tilt or 1-Axis Tracking System:		
Array Tilt (degrees):	31.8	(Default = Latitude)
Array Azimuth (degrees):	180.0	(Default = South)

Energy Data:

Cost of Electricity (cents/kWh):	Default = State Average

Calculate HELP Reset Form

PVWatts AC Energy & Cost Savings

Cautions for Interpreting the Results

(Type comments here to appear on printout; maximum 1 row of 80 characters.)

Station Identification	
City:	El_Paso
State:	Texas
Latitude:	31.80° N
Longitude:	106.40° W
Elevation:	1194 m
PV System Specifications	
DC Rating:	4.7 kW
DC to AC Derate Factor:	0.770
AC Rating:	3.6 kW
Array Type:	Fixed Tilt
Array Tilt:	31.8°
Array Azimuth:	180.0°
Energy Specifications	
Cost of Electricity:	9.7 ¢/kWh

Results			
Month	Solar Radiation ($kWh/m^2/day$)	AC Energy (kWh)	Energy Value ($)
1	5.39	583	56.55
2	6.13	582	56.45
3	6.96	734	71.20
4	7.33	718	69.65
5	7.20	709	68.77
6	7.25	672	65.18
7	6.82	653	63.34
8	6.65	642	62.27
9	6.82	641	62.18
10	6.72	679	65.86
11	5.67	578	56.07
12	5.43	596	57.81
Year	6.53	7788	755.44

Output Hourly Performance Data Output Results as Text

Figure 3.2.3: Sample PVWatts Output for El Paso, Texas (NREL 2013c)

PVWatts estimates that this same power output can be achieved in Phoenix, Arizona with a 4.82 kW system which is 3% larger than the El Paso case, and in Portland, Oregon a 7.65 kW system would be required which is 63% larger. This is due to the solar insulation differences, as illustrated in the following Solar Insulation map from NREL

(2008), and summarized in the following solar insulation figure 3.2.4 and comparative system performance table 3.2.1:

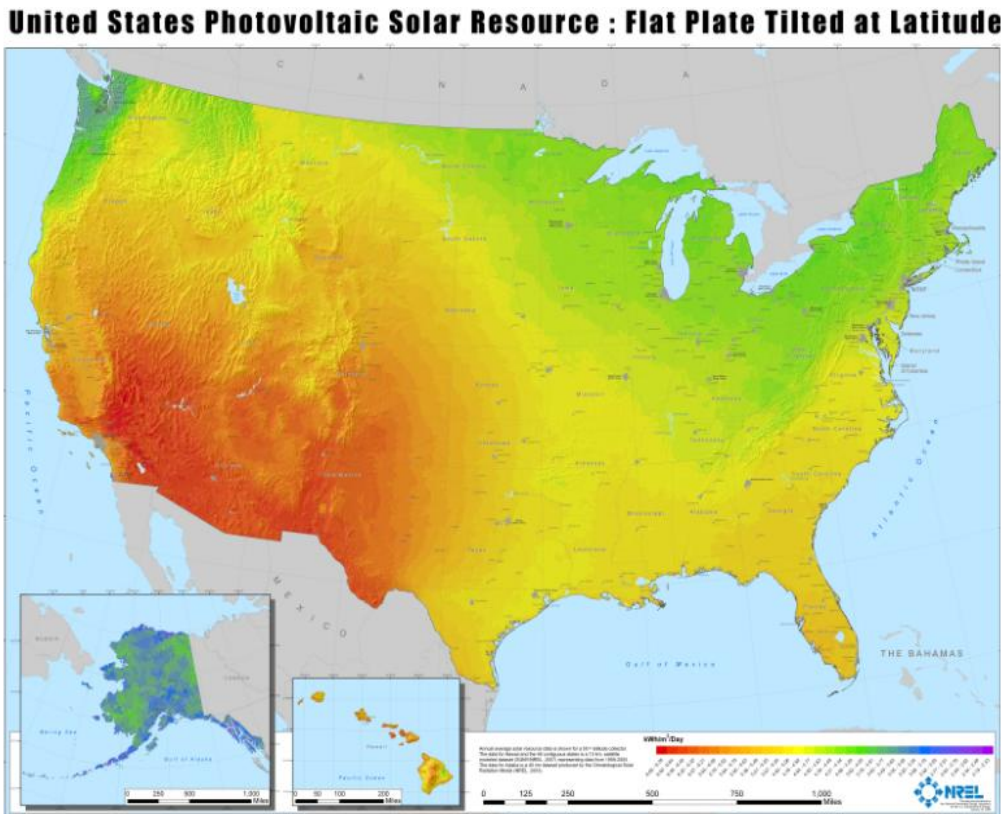


Figure 3.2.4: United States Photovoltaic Solar Resource: Flat Plate Tilted at Latitude (NREL 2008)

Table 3.2.1: PVWatts Estimated Fixed Photovoltaic System Size Comparison for the Same Annual Generation. (NREL 2013c)

	El Paso	Phoenix	Portland
Estimated System Size to Achieve 7788 kWh per Year Output (kW)	4.7	4.8	7.7
Relative size to baseline (4.7 kW)	100%	103%	163%

- Electricity price increase is dynamic and assumed 3.5% over the past 12 years: This value was derived by taking the average Residential Electicity Price history percent change over twelve years, as shown in the following figure 3.2.5 from the Energy Information Administration:

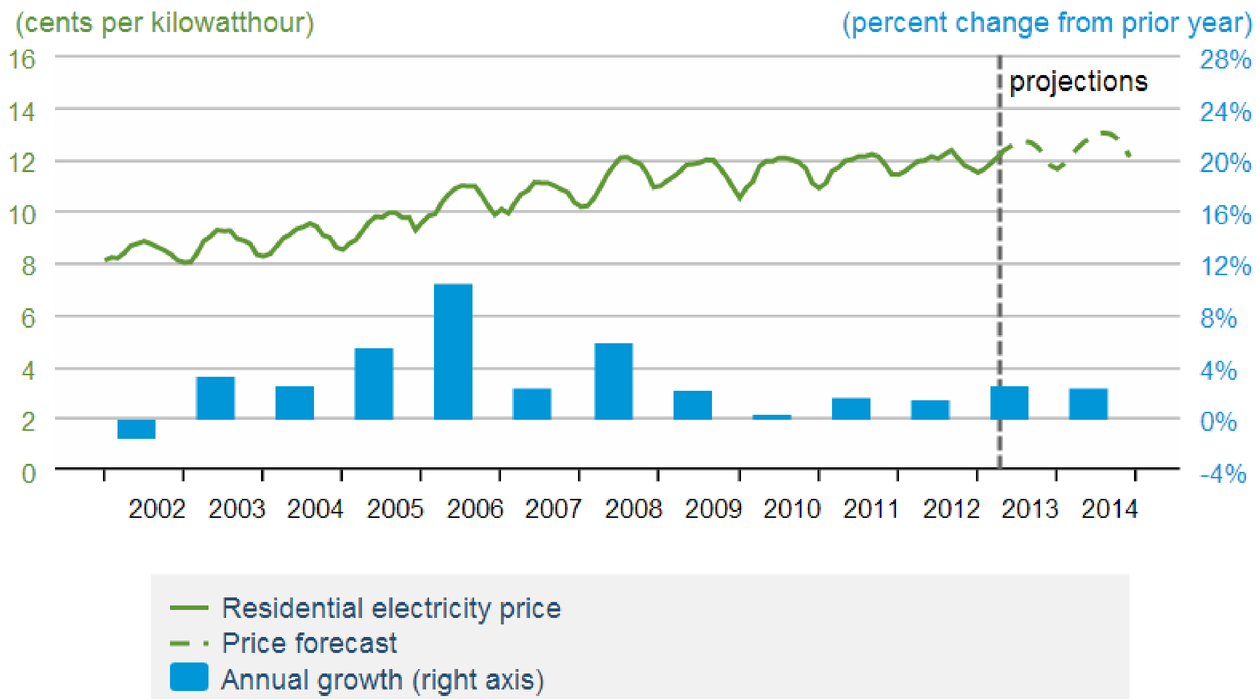


Figure 3.2.5: U.S. Residential Electricity Price, Short Term Energy Outlook (EIA 2013c)

- Establish kWh electricity retail cost purchased by each Community: Standardized assessment of unit electricity transaction cost is necessary for objective comparison of the case study cities. Fortunately, the Department of Energy continuously monitors state electricity costs and publishes a summary. This study incorporates their work as a basis for NPV calculations of unit sales to determine the investor value of residential photovoltaic investment. Key to

this assumption and data is that each targeted case study must operate under similar financial structures, and fortunately they do (discussed above).

Each test Community operates under the Net Metering concept where electricity use and generation are netted each billing cycle. Further, a key assumption is that no 'sell back' to the utility is considered. Generation and consumption is thereby strictly analyzed under retail electricity rates to allow for more direct comparison. Metrics are based on statewide retail rates, and connection fees are not included as a grid tied system considers these costs as neutral between the two options of centralized and distributed grid-tied generation. Governed by these assumptions, analysis can now consider current state, Utility residential retail electricity unit cost as a comparative basis for each case study:

Table 3.2.2: Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State, December 2012 and 2011 (EIA 2013b)

Census Division and State	Residential		Commercial		Industrial	
	December 2012	December 2011	December 2012	December 2011	December 2012	December 2011
Arizona	10.36	9.98	8.98	8.67	5.95	5.86
Oregon	9.77	9.57	8.16	8.06	5.47	5.42
Texas	11.06	10.89	7.98	8.49	5.72	5.80
U.S. Total	11.62	11.40	9.82	9.77	6.54	6.51

- Inflationary effects on cash flow are considered equal as they would have identical net present value impact on startup costs and electricity offset expense.
- Each case study is assumed to operate under a Net Metered, grid-tied scenario: This assumption is validated by the availability of specific rate schedules: Portland areas served by PGE specify net metering of residential installations under schedule 203 (PGE 2011); Phoenix areas with electricity delivery by APS are managed under Arizona Administrative Code, Title 14 for Public Service Corporations, article 23 (Arizona Department of State

2009); and El Paso which is completely serviced by EPE is governed by Texas Senate Bill SB1910 and is designated as Rollback Net Metering offered through the EPE Rate 48 (TX SB1910 2013).

- Connection fees are considered equal between solar system ownership and engaging utility electricity delivery under the net metering scenario, and are not considered in the financial modeling based on the confirmed net metering platforms for each case study.
- Assume all electricity generated by the solar system is consumed by the Community investor.
- Assume systems are purchased directly by the Community member. Third party funding options are not considered. Remote, third party investors can enable markets but may channel potential income out of the Community. These investment vehicles are not considered in this work.
- Establish local Net Present Value, Investment Rate of Return, and Payback Period for residential PV generation investment: As presented in the following figures, financial reviews represent returns a residential grid-tied photovoltaic investor could expect when compared to electricity purchase from the centralized Utility offering. Analysis is performed over a 20 year period based on current performance warranties offered by solar equipment manufacturers for crystalline silicon panels and modern inverters. The charts are constructed to illustrate a range of initial purchase price based on nameplate wattage from $0.50 to $6.00 per Watt. The left vertical axis defines the investment rate of return (IRR) of the cash flow. The right vertical axis defines the expected payback period of initial investment, which is the number of years required after purchase to recover initial investment and begin receiving 'free' electricity if possible.

The three test cases were analyzed under the aforementioned assumptions and the data is presented in the following charts:

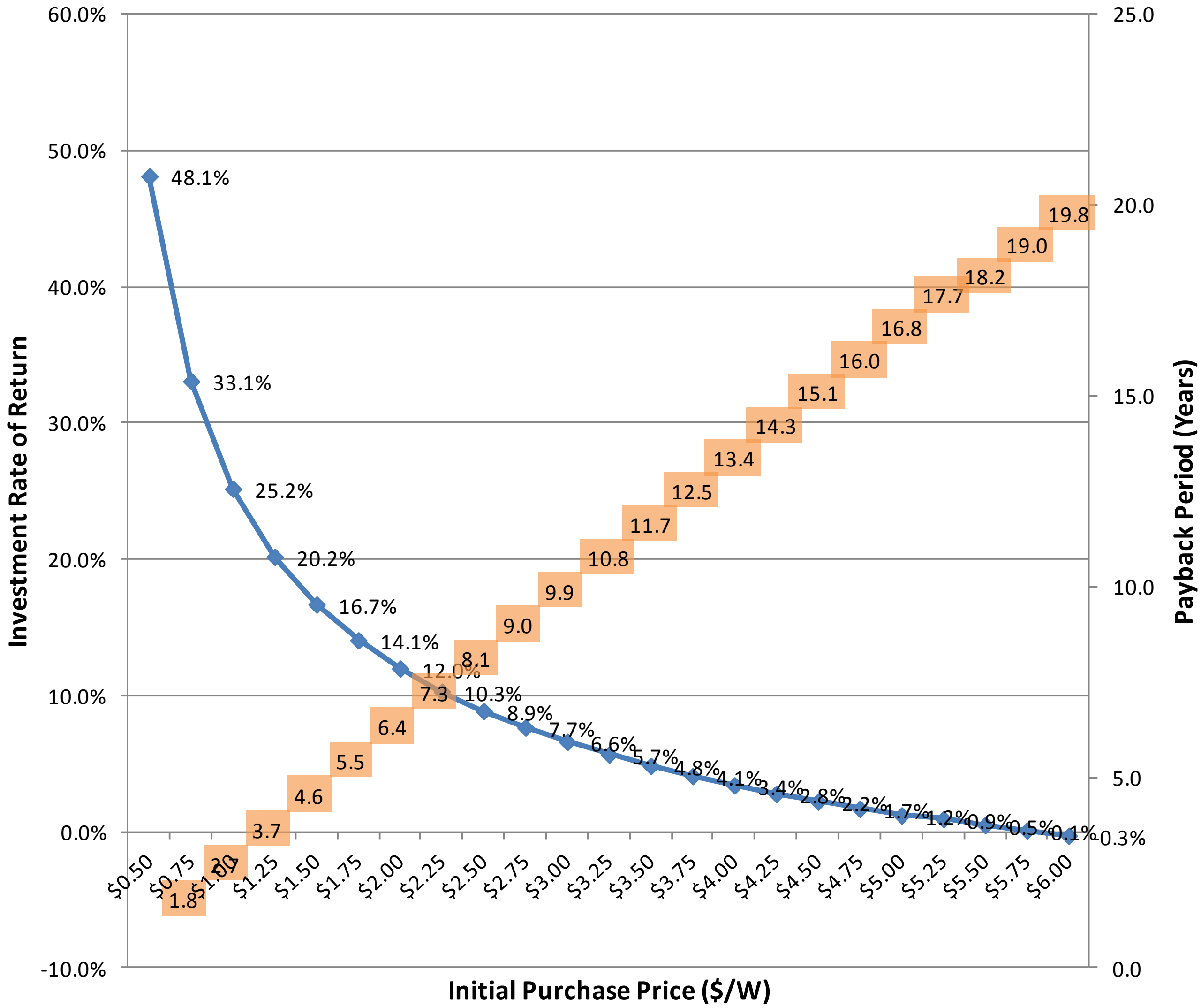


Figure 3.2.6: El Paso, Texas Community member Financial Assessment test case for Residential Photovoltaic investment versus Utility electricity purchase

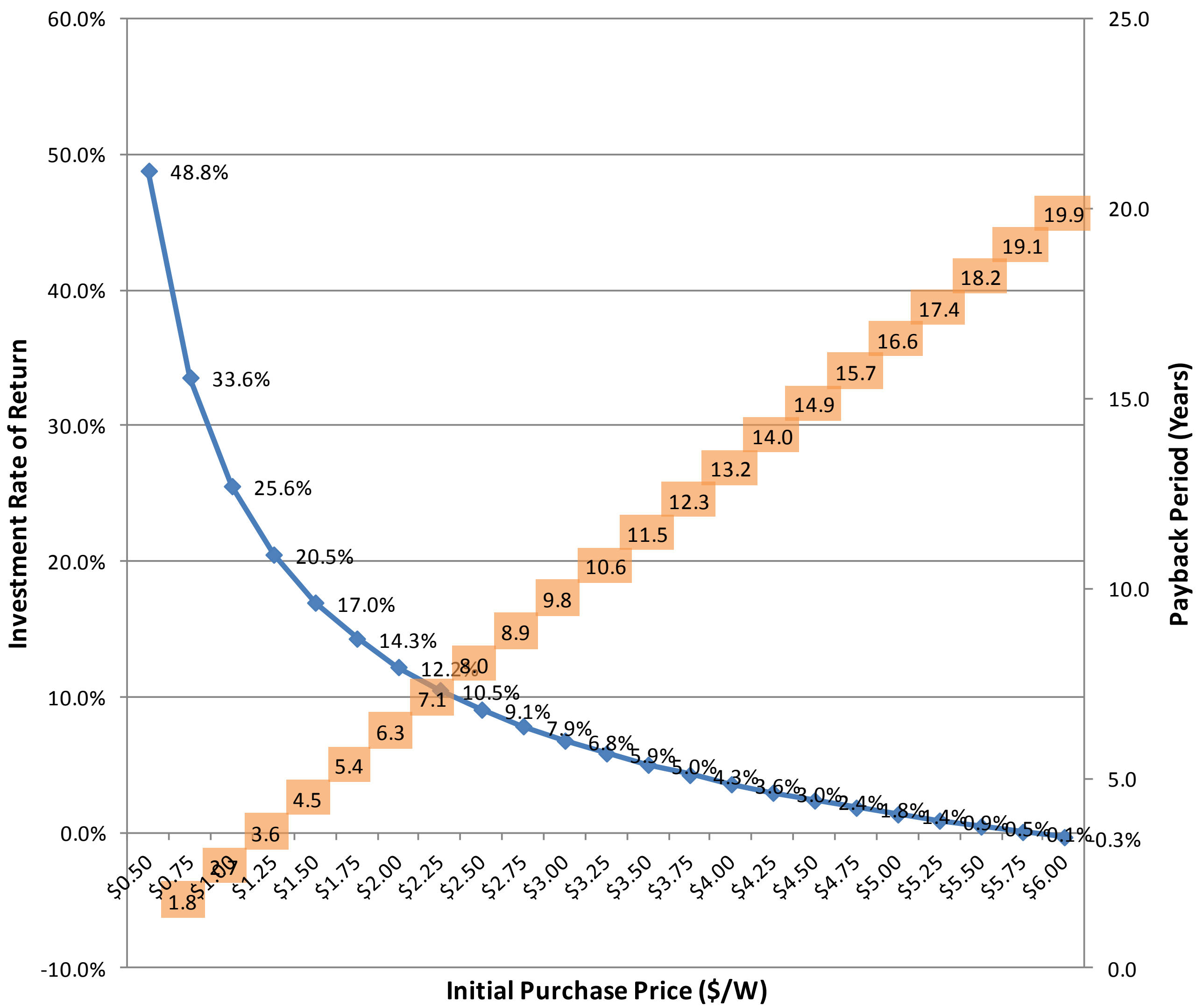


Figure 3.2.7: Phoenix, Arizona Community member Financial Assessment test case for Residential Photovoltaic investment versus Utility electricity purchase

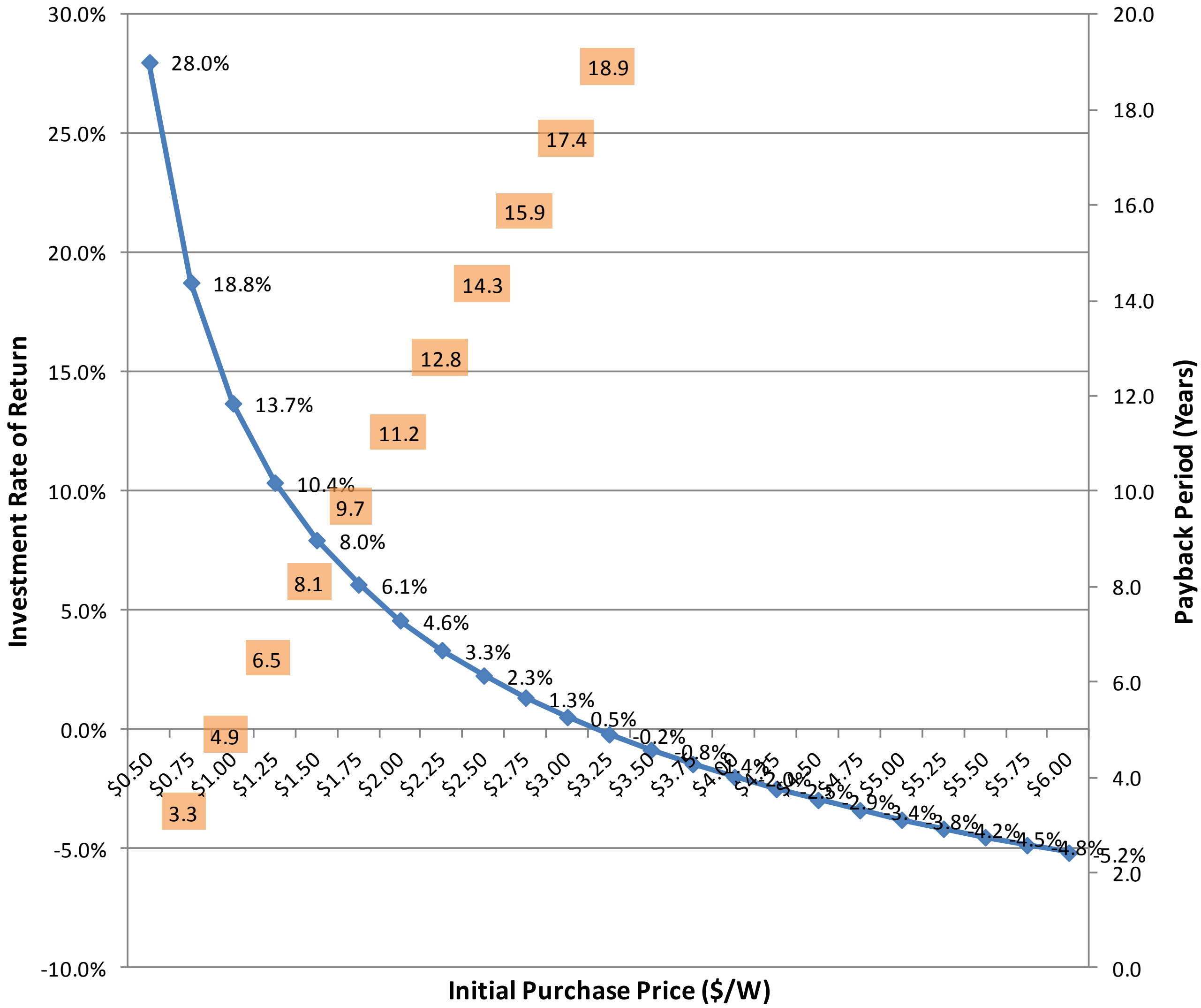


Figure 3.2.8: Portland, Oregon Community member Financial Assessment test case for Residential Photovoltaic investment versus Utility electricity purchase

Community members in each case will likely have a different perspective of risk and return for their respective investment, and these charts allow participants to review this financial balance.

However, in this application across the three cases requires a baseline purchase price of an average system to establish Community benefit based on adoption.

A single, consistent source for installation cost comparison per Watt between the states is available in the following figure, reproduced from (Berkley 2012):

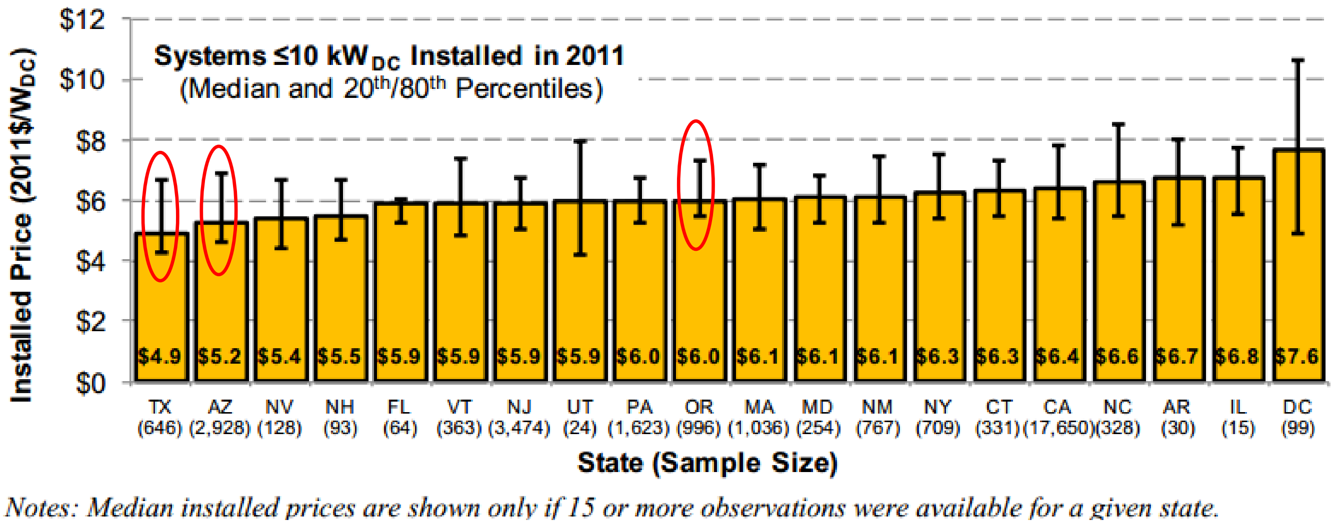


Figure 3.2.9: Installed Price of Residential & Commercial PV Systems by State (≤10 kW Systems) (Berkley 2012)

As with much of the data for this industry delays from data acquisition, analysis, and publication result in a gap between the realities of pricing in the current market versus what is reported. The above chart indicates the difference in the average pricing for per Watt solar installation across Texas, Arizona, and Oregon in that ascending order as indicated. The data demonstrates that pricing varies depending on installer, services included, and complexity of the actual installation.

One clear fact is that photovoltaic system prices continue to fall. As is illustrated in the following figure, the observed trend in pricing distribution and yearly reduction as reproduced from the 2012 Berkley study (p. 16):

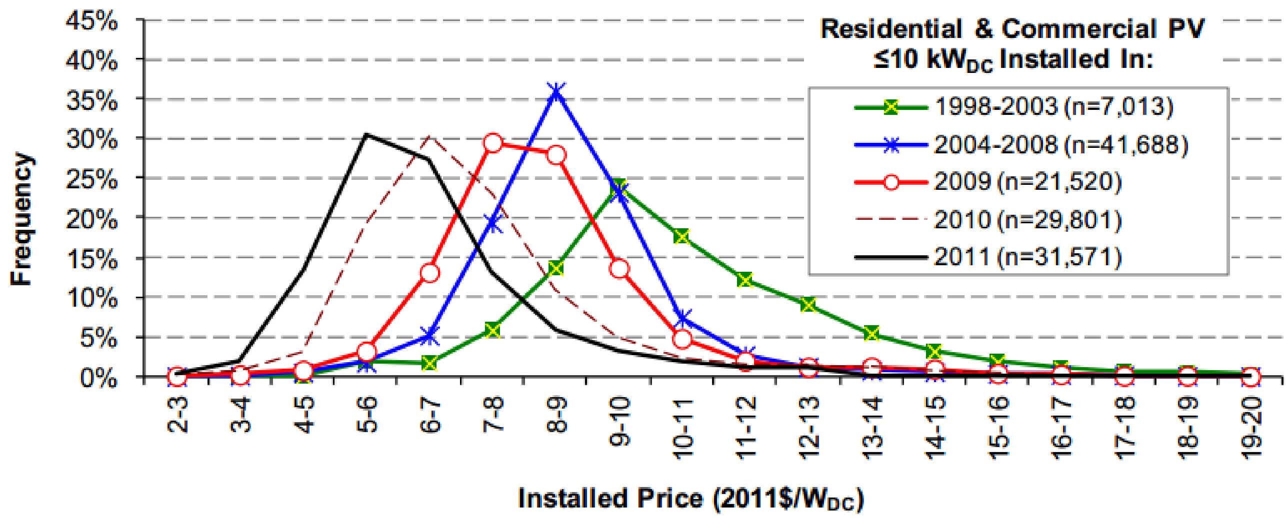


Figure 3.2.10: Installed Price Distribution for Residential & Commercial PV (≤10 kW Systems) (Berkley 2012)

As a recent purchaser of solar system in December, 2011, the researcher is aware of local pricing structures in El Paso, Texas. As the researcher purchased a residential PV system in late 2011, more intimate knowledge of actual pricing structures is available for the El Paso, Texas test case. The purchase price of a residential grid-tied photovoltaic system was $3.50 per Watt, which was considered highly competitive at that time in the El Paso market. Note that Berkley cost results presented above are statewide averages, and that they may vary based on local influences.

Utility Individual Motivation

Residential grid-tied photovoltaic installations affect incumbentUtilities in complex ways by offering both risks and benefits. Under the Porter consideration and for this assessment, these factors can be identified when considering the rivalry impacts of 1) substitute technologies and 2) the power of buyers.

Applying the Porter model, Utilities are faced with two concerns regarding Community adoption of distributed generation: First, each kilowatt-hour of electricity produced by the Community is revenue

loss that could threaten the Utility 'natural monopoly' motivation discussed earlier. The second threat to the Utilities is that under grid-tied customer agreements, the Utility is obligated to provide electricity on demand by the customer. Risks of decreased generation from cloudy days, air quality, system outage and poor performance of the customer solar system force the Utility to hold capacity idle to react rapidly to events and deliver electricity on demand.

Community adoption of residential solar could however offer benefits to the Utility. Distributed solar generation can offset electricity peak demand and reduce variability in business operation during peak hours. Often, these peak kWh's are the most costly to the Utility and can be be sold at a financial loss. By levelizing demand through 'high consumption' customer conversion, Utilities can potentially gain more profit for the kilowatt hours they sell albeit at decreased revenue. In addition to more profitable unit sales, they may also be able to defer operational complexity and infrastructure costs as variable peak loads are reduced and levalized for more continuous, predictable, and profitable operation.

This concept of increased profitability through stable operations in this industry is documented in a report issued by the Brattle Group for the Electric Reliability Council Of Texas, Inc., or ERCOT, in 2012. Brattle (2012) analyzed impacts of solar based residential adoption in Texas and determined that the Utilities and Community improve prosperity through residential photovoltaic adoption. In the published report "Potential Impact of Solar PV on Electricity Markets in Texas" by the Brattle Group (2012), they suggest and quantify that increasing distributed generation eliminates high marginal production cost for the Utilities and increases their profit. A key finding is that when demand is reduced at peak periods, marginal operational cost is also reduced. Visually, this is demonstrated in the following figure 3.2.11 from Brattle (2012):

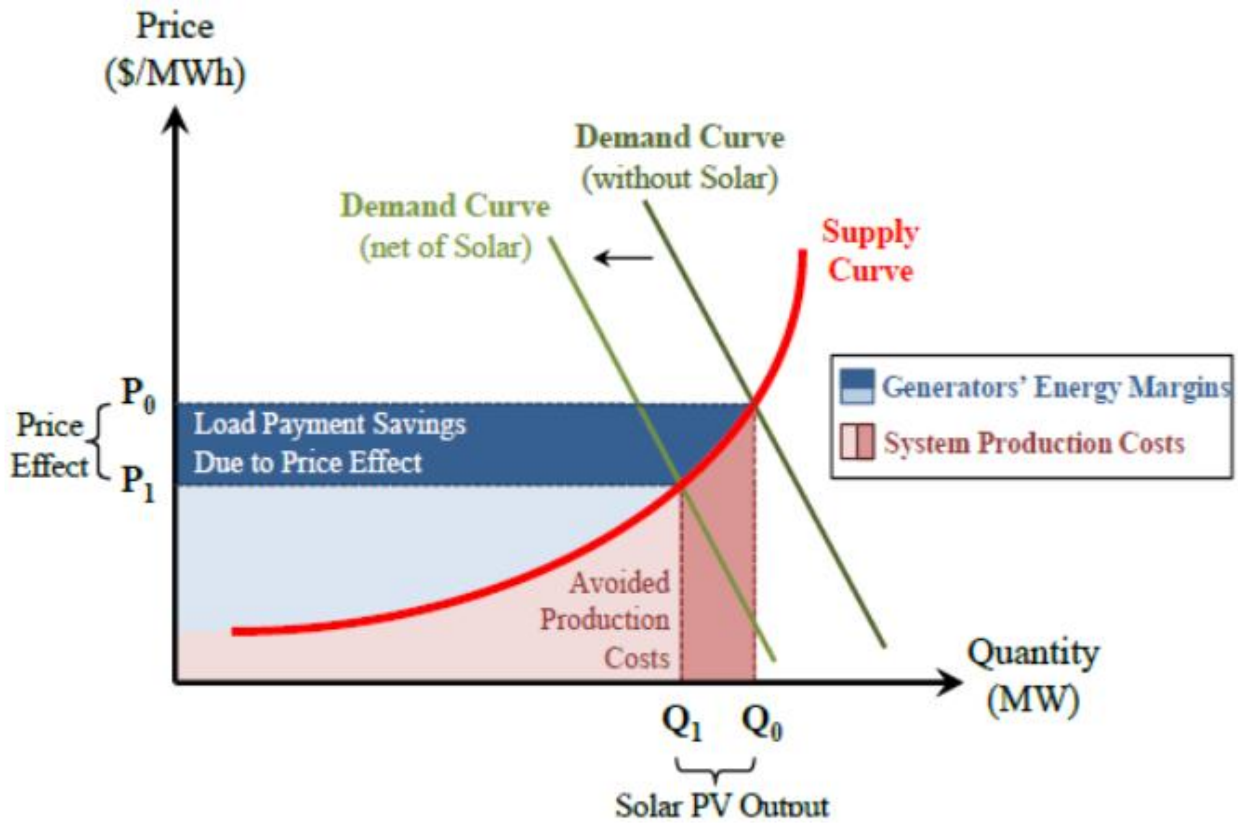


Figure 3.2.11: Theory of Energy Price Effects due to Solar PV and Related Customer Benefits (Brattle 2012)

Under this economic concept reproduced above, distributed solar generation has a direct effect on centralized electricity prices and profitability (Brattle 2012). Per the Brattle diagram, if the quantity of centralized electricity production decreases due to distributed solar production, unit peak power electricity price will decrease due to the exponential relationship of price to production cost. The result is a lower unit generation cost based on these theories.

The Brattle report expanded this concept to apply ERCOT data to better quantify the impact of these savings based on specific technologies used to generate electricity. As defined in their study, the Brattle Group states that "under the model-based approach, we used publicly-available data to construct energy supply curves for the Texas wholesale energy market based on the estimated variable costs of all available generation sources, ordered from least expensive to most expensive. Given the demand in each

hour, we then estimated energy prices by finding the most expensive generator needed to meet that demand in that hour." (Brattle 2012, p. 7)

The Brattle study demonstrates that marginal costs for high cost peak demand electricity generation such as gas fired, rapid startup turbines are more expensive than constant delivery, steady state equipment. Some factors affecting pricing are that unit generation uptime is lower, efficiency is reduced by different technology optimization, and incremental generation cost increases for high demand generation or 'Peaker' units. Details are quantified by Brattle in the reproduction Figure 3.2.12 below:

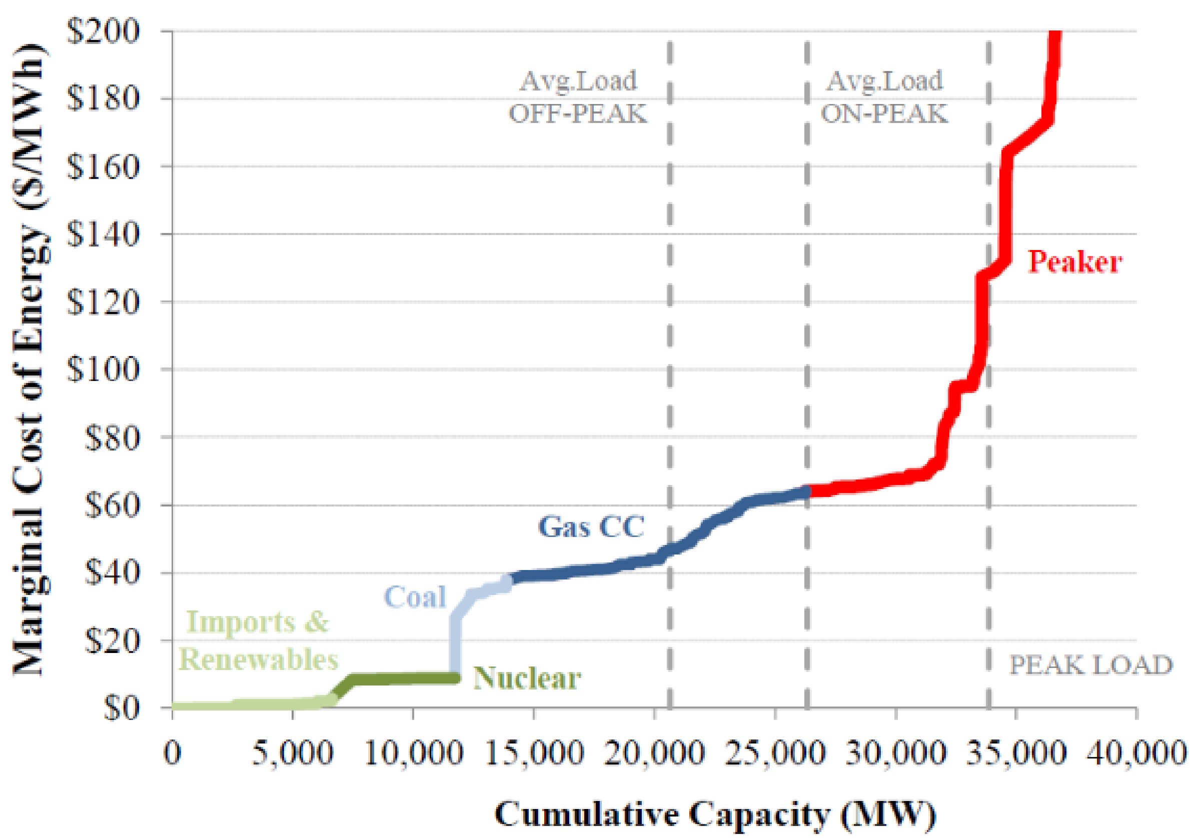
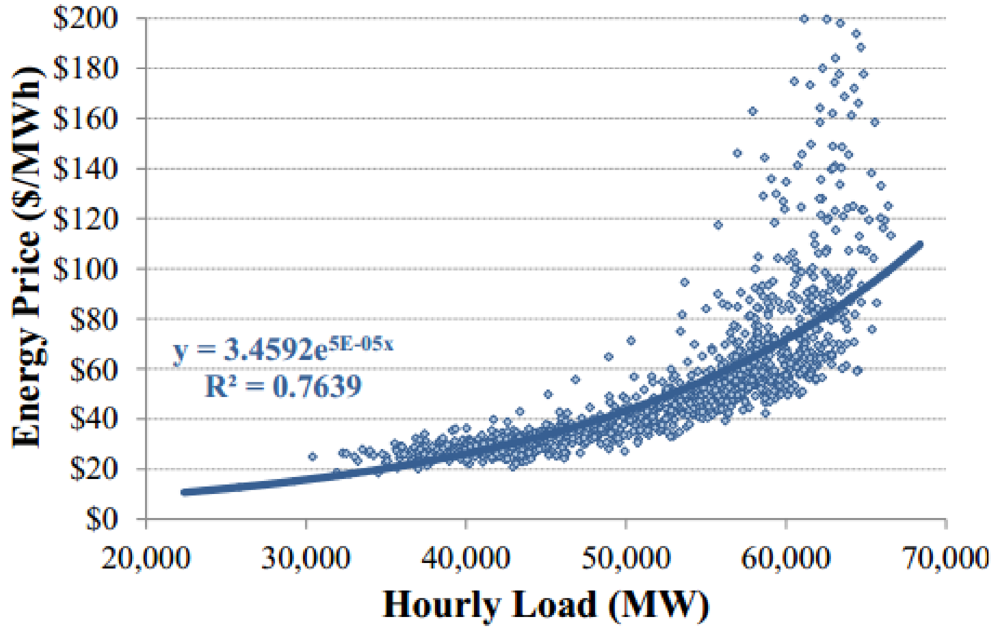


Figure 3.2.12: Illustration of Supply Curve Used to Estimate Energy Prices (Brattle 2012)

Peak demand variability imposes incremental cost to the centralized Utility in Texas. The exponential nature of Marginal Cost to Cumulative Capacity suggests that the Utility suffers a loss on sales when peak demand electricity coverage is generated and delivered.

As a basis for this study, it is assumed that a Utility faces profit erosion for generation between peak load and average on-peak. In the above figure, that capacity level is roughly 20% below peak based on ERCOT data from Brattle. The general assumption is that during peak hours approximately 20% of generation capacity represents profitability loss. In addition, the marginal cost for that segment of electricity generation ranges from $0.06/kWh to $0.12/kWh exponentially. Contribution from distributed generation can reduce the delivery requirements that, for the peak demand involving 'peaking' generation units, are more expensive than the retail sale rates utilities obtain through billing. Stated alternatively, Utilities can actually increase profit margin of their businesses by losing business to distributed generation purchased and maintained by the Community.

This observation was further developed by assessing the relationship between hourly day-ahead energy prices versus regional demand. The exponential relationship between load and energy price was supported through observation, and again highlighted the concept of a 20% peak generation cost risk to the Utility as presented in figure 3.2.13 (Brattle 2012):



Source: Calculated based on the hourly data compiled by Ventyx, the Velocity Suite.

Figure 3.2.13: Relationship between Hourly Day-Ahead Energy Prices and Regional Demand in ERCOT (for the period of June 2011 through August 2011) (Brattle 2012)

In ERCOT market electricity pricing demonstrates a 20% of peak load range where profitability is subject to variability risk. This range falls between approximately 55,000 MW to 65,000 in ERCOT, and pricing from $40/MWh to $200/MWh. Within this chart region, visual assessment of the area centroid was conducted and determined an average peak power market price Utilities would pay to deliver electricity. Conservatively, generation costs are roughly $0.13/kWh on average for peak electricity delivered in the upper 20% band of peak in ERCOT. For these parameters, two rules of thumb for this study can be made: (1) ERCOT utilities witness peak power generation variability and increased cost in the upper 20% delivery at peak periods, and (2) suffer an average profit loss of nearly 20% retail market price for each energy unit sold when delivering at peak power in ERCOT (Brattle 2012). For Texas, average retail price is $0.11/kWh and average peak generation cost is estimated at $0.13/kWh

indicating a unit sale loss. A representative Load Forecast versus Actual is provided below for ERCOT reference:

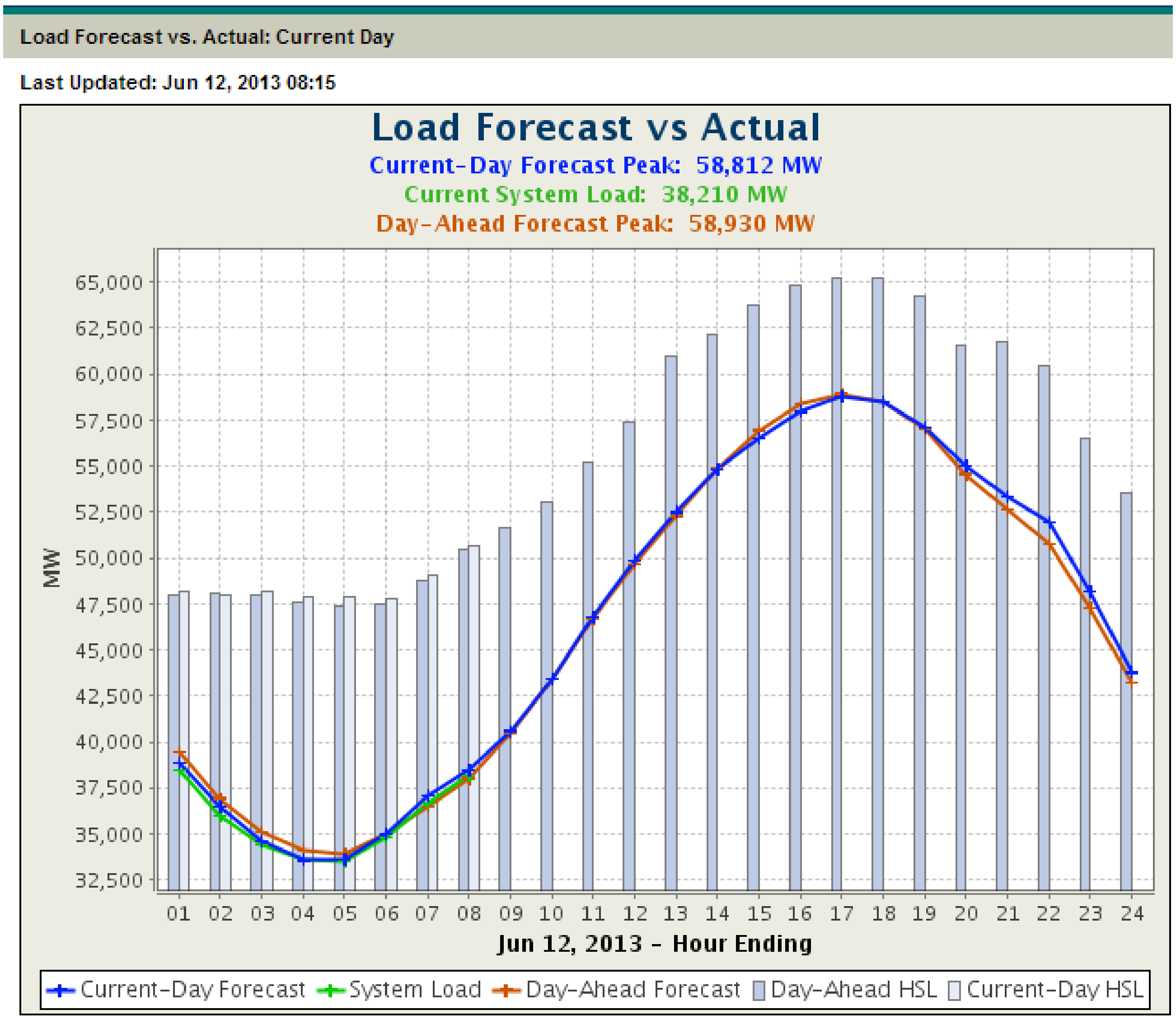


Figure 3.2.14: ERCOT Load Forecast versus Actual (Reproduced from ERCOT, 2013)

Utility operational statistics and analyses are not widely published, and the Brattle report for ERCOT is the only report found in the public domain to provide the level of detail needed to quantify

Community adoption impact on Utility electricity profile profitability. For the ISDMF application, Brattle report findings are distilled into general value impacts, and percentages or 'rules of thumb' established through this analysis are applied to the published case study data.

Integration of state retail data with the ERCOT operational data demonstrates that when applying conservative retail electric rate estimates by state, peak generation under a centralized model can operate at a loss. The myriad of mechanisms to solve this problem are difficult to manage, and range from Utility driven rate cases to modify electricity billing strategies, research to justify them, rate case filing, and continued profitability erosion. A potential reality is that rather than internally react to revenue erosion, Utilities may enhance their position by investing in and engaging the Community cooperatively to eliminate marginal losses on peak unit sales.

Armed with the previously established 'Rules of Thumb' for assessing utility profitability as an individual player, a directional approximation can be made regarding Utility profitability opportunity. Prior to presenting the actual data for each case study, a disclaimer is needed to clarify again that these estimates were derived by assessing the example of ERCOT from the Brattle Report (2012). Each case study has different generation and distribution infrastructure, and may have varying financial impacts as a result. However, Federal and State regulations ensure some consistency in Utility equipment and margins, as do wholesale markets and technology options. Under those stipulations, the defined 'Rules of Thumb' will be applied to gain insight toward individual Utility motivations in the Framework application. Directional estimates presented herein become exact with actual data not available in the public domain.

In the case of El Paso, the most current and applicable information found to revenue and profitability impacts is found in figure 3.2.15. This data indicates a peak demand of 1620MW at 3:00pm. A twenty percent reduction of that peak value (per Brattle and ERCOT study findings) is rounded to 1300MW, which implies that 320MW of generation poses profitability risk to El Paso Electric.

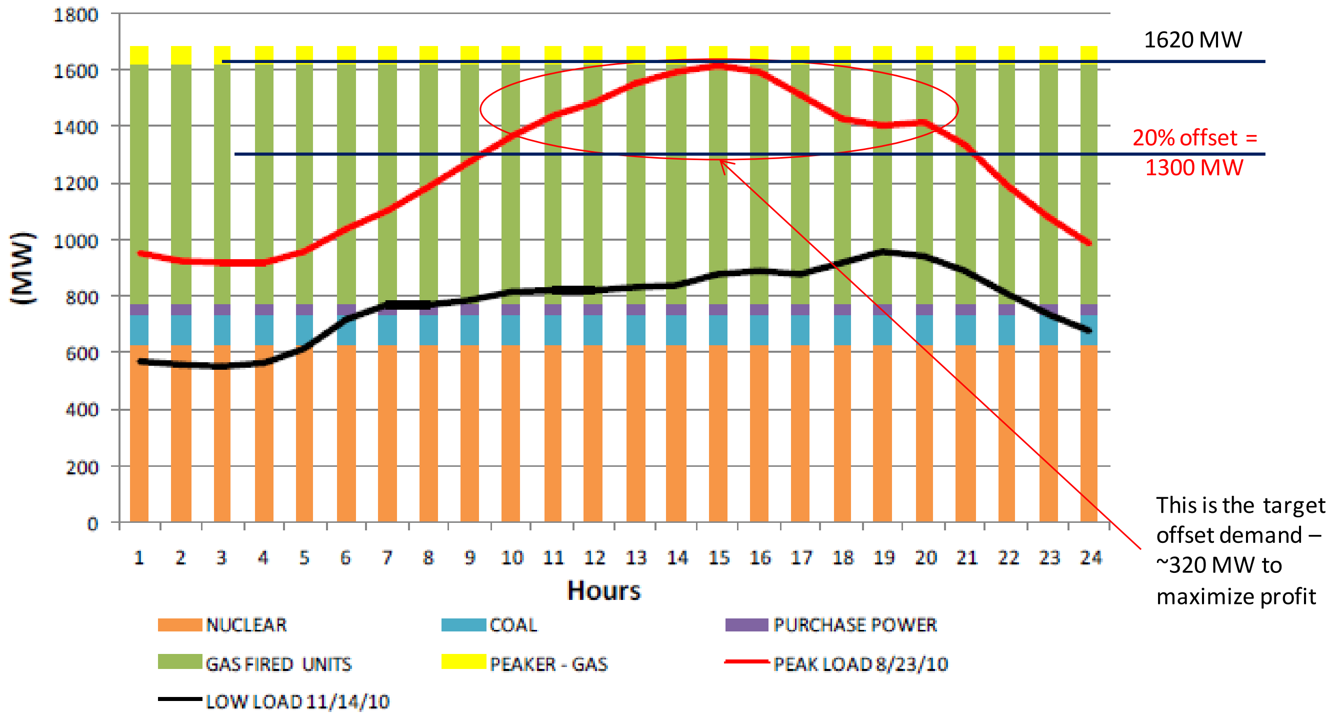


Figure 3.2.15: El Paso Electric Summer Demand versus Production (reproduced from EPE 2011, p. 14)

'Peak' load roughly occurs between 9:00am and 9:00pm, with an average load of about 160MW. This implies a 160MW load for approximately 12 hours, 365 days per year, or 700800 MWh/Year. This number will be halved to accommodate lower demand winter seasonal variance and continuous operational improvements, resulting in a total unprofitable GWh of electricity sales for EPE of 350GWh/year. If a $0.02/kWh loss is attributed to these transactions under the rule of thumb, EPE currently pays $45.5 million to achieve a revenue stream of $38.5 million. This indicates an approximate loss of $7 million annually on those peak production units.

In the case of Phoenix, the Arizona Public Service Integrated Resource Plan presents the necessary data to perform a similar assessment, and is included as figure 3.2.16. The APS load requirements in 2012 are published at 8300MW for peak load. A 20% reduction of that peak load is 6640MW. Applying the previous assumptions as used for El Paso, APS currently spends an average $0.1243/kWh to collect $0.1036/kWh. Assuming similar daily peak demand curve shape between Phoenix and El Paso, the peak demand delivery under consideration is 1660MW.

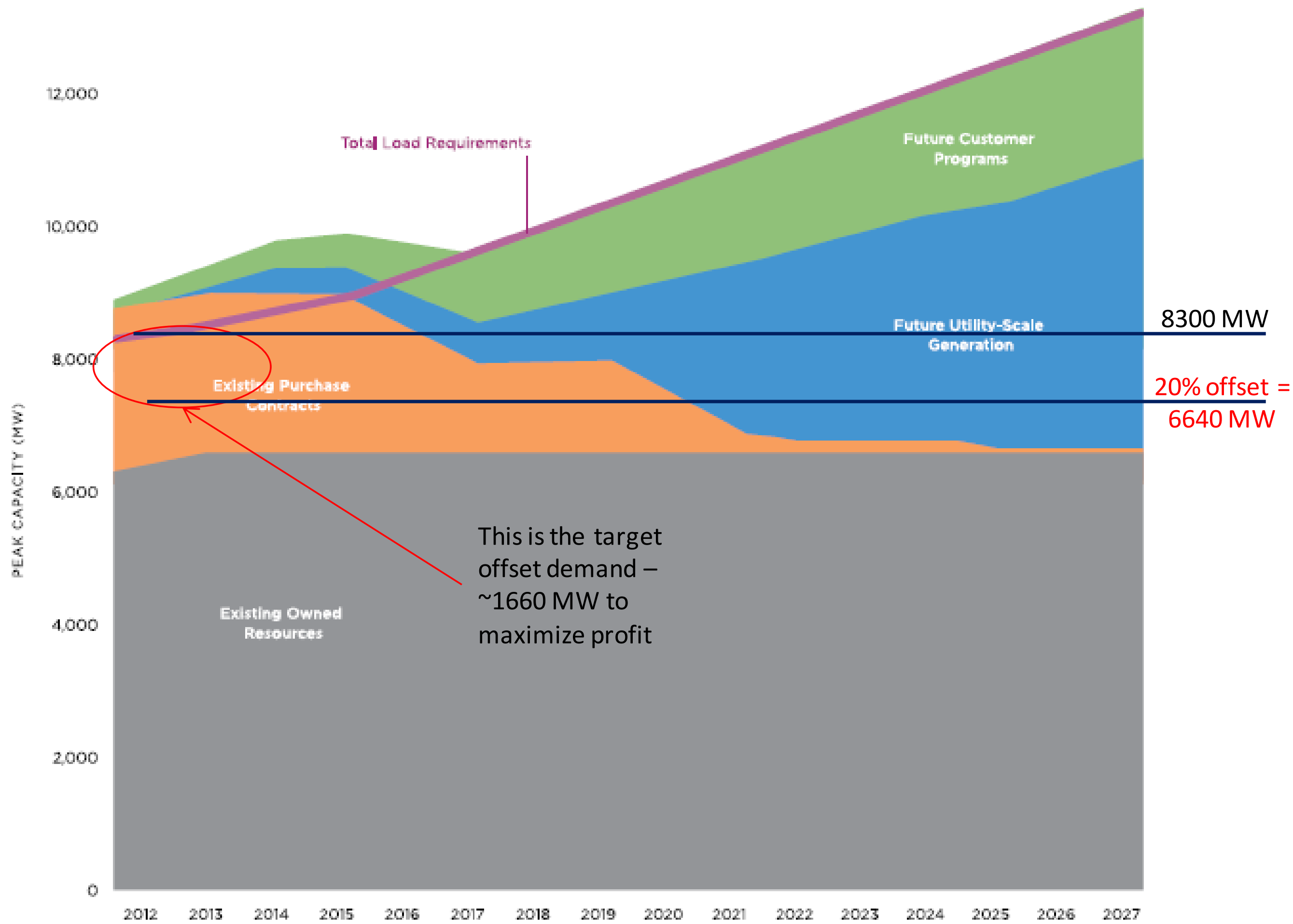


Figure 3.2.16: Arizona Public Service - Integrated Resource Plan, Summary of Resource Additions (Reproduced from APS 2011, p.7)

Assuming average delivery during that time, the demand for the 12 hour period is 840MW per day for one half of a 365 day year. These assumptions indicate that 1,839.6GWh are subject to peak profit erosion risk. Applying retail pricing and a 20% loss on sales, APS pays $228.3 million to generate $190.5 million in revenue, and realizes a $36.8 million loss for those unit electricity sales.

The final case study for this Framework application is Portland General Electric. Their demand curve is reproduced as figure 3.2.17 (PGE 2013). In 2012 PGE had a reported peak demand of

2300MW. Applying identical logic and assumptions as with the previous test cases, 20% of peak demand for PGE is 460MW. Average delivery would be 230MW, 12 hours per day, for one half of the year which is 503.7GWh. Retail electricity rate in Oregon for December, 2012 is listed at $0.0977/kWh. Applying the developed 'Rule of Thumb', production cost for those same saleable units is $0.1177/kWh. Under these assumptions and data, PGE would then pay $59.3 million to receive revenue of $49.2 million for a net loss of $10.1 million on those unit sales.

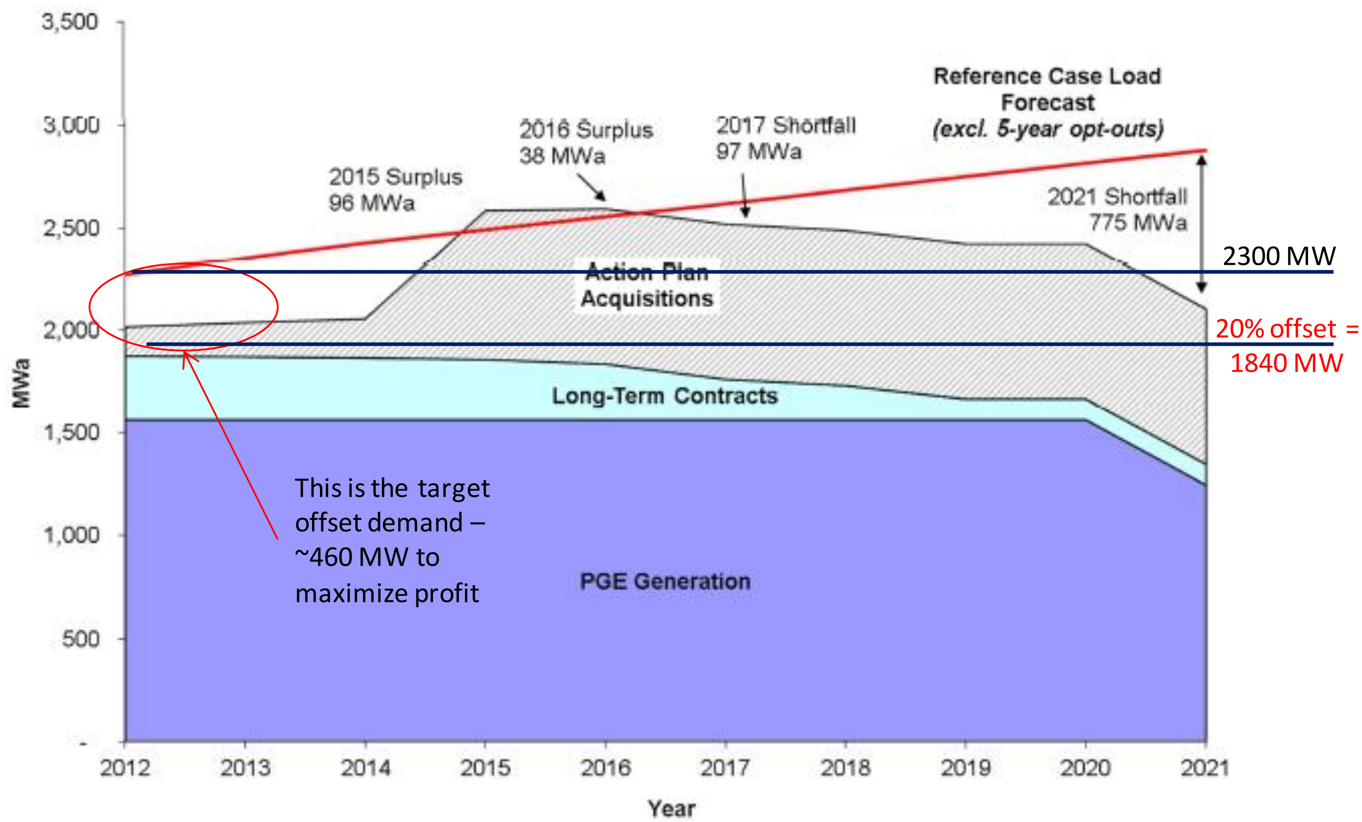


Figure 3.2.17: Portland General Electric, Energy Load-Resource Balance to 2021 after Action Plan Acquisitions (reproduced from PGE 2013)

These financial estimates indicate that Utilities benefit economically by engaging Community efforts to adopt distributed grid-tied residential photovoltaic installations. Many complex factors affect these results, and again they are estimated and directional in nature from publically available data

sources. While directional in nature, these data provide a standardized basis for comparison between case studies.

Beyond financial benefit of reducing peak generation, Utilities can enhance community goodwill and environmental contribution by supporting distributed generation adoption. Renewable electricity platform embracement also provides benefits over local fossil fuel generation and distribution by reducing water consumption and emissions, and promotes community growth through capital preservation and increased disposable income. Specifically, residential photovoltaic adoption supports 'natural' monopolies to operate at enhanced financial margins, improved carbon footprint, and reduced water consumption while simultaneously benefitting from the Community to absorb initial investment. Further development of these topics will be discussed in the Cooperative Interaction of the Utility and Community section 3.4.

3.3. Competition between Community and Utility

With the Community is now enabled via technological advancement of distributed electricity options, they are now able to decide if residential grid-tied photovoltaic investment adds sustainability value. In competition, Communities must primarily evaluate if the commodity they purchase can be reliably obtained at a lower cost, and secondly if auxiliary benefits are possible for community prosperity. As an incumbent supplier, Utilities must consider effects of losing revenue while retainging some level of control of their grid structure to satisfy contractual obligations. Utilities weigh those potential risks against unit sale profitability growth, goodwill development, and environmental impacts.

Key to player strategies is that business solutions to enable sustainability should encompass and leverage core benefits to each player motivation. A steadfast perspective of 'competition' can be viewed as a misnomer; rather, 'competition' in a transparent cooperative environment can improve the position of both players, as was developed in section 2.2.3 - Current State and Collective Action - Common Pool Resource / Social Ecological Systems in the Literature Review. Under relatively high residential photovoltaic adoption levels likely outcomes benefit both players if they operate together. However, Community willingness to participate, and morality of greed and myopic thinking can govern

proliferation of optimal solutions. These Community actions may result in tragedy through ever increasing electricity delivery cost, scarcity, and adverse environmental effects under the status quo.

From a competitive perspective, the individual residential photovoltaic investor must consider an array of resource impacts to arrive at a decision to invest. Competitively, the first category is often communicated as installation cost and investment return. Secondly, Community members may be motivated to contribute to general environmental improvements enabled through renewable energies. Some key decision factors are air quality, water availability, energy security, and aesthetics.

As a second player in the game, Utilities are concerned with the same issues as the Community, but are also forced to include consideration of revenues and monopoly preservation. Decision-making then evolves both players to arrive at the most sustainable action. Under these strategy challenges, a Framework such as the ISDMF to organize those considerations becomes paramount.

Competitive decision-making factors are developed in the Individual Behavioral Models (section 3.2) and Cooperative Interaction between Community and Utility (section 3.4) with data and references. While it can be perceived that substituting incumbent centralized with distributed generation is a direct threat to Utility business, issues already discussed in this section indicate that adoption to a profitable limit actually enhances business performance for both Utilities and the Community. Under this pretense, competition then only becomes fierce and detrimental when 'Win-Win' scenarios are surpassed by individual narcissistic interests.

As was developed in section 3.2, residential photovoltaic adoption is not competitive but can actually beneficial to each player across the three communities. These estimated adoption constraints ensure benefits to both players through cooperation, and are used as the basis to develop sustainable levels of residential grid-tied photovoltaic generation incorporation to the electricity generation platform. Cooperation between the Community and the Utility is perhaps the most important element to create a sustainable electricity solution, particularly when each player recognizes the immediate individual benefits available beyond current state. (Ostrom 2009) Electricity consumers adapt to pricing models determined by Utilities and approved by the regulating bodies, and their decisions are driven by the level of cooperation offered by the Utilities to stimulate individual investment based on personal

financial gain and individual values. Accordingly, decisions to incorporate distributed generation technologies by the Community are largely based on the transparency, accuracy, and support offered by the respective Utility.

Baseline estimates for market size in terms of electricity generation and financial impacts were developed in section 3.2. Based on those numbers, local community impacts are the next items to consider when assessing cooperative engagement. As was stated in the Methods introduction , data assumptions made in this study provide directionally accurate assessments to test Framework validity.

Adoption estimates determined using 'Rules of Thumb' provide definitive comparison levels among the case studies, as adoption level determines the centralized electricity model shift based on distributed, residential grid-tied photovoltaic generation. The level of adoption to calculate these elements are based on estimated residential market when the state kilowatt-hour retail rate is less than the estimated utility cost to deliver the marginal electricity unit sale. As will be subsequently developed, this analysis considers migration from centralized, gas fired generation to distributed residential grid-tied photovoltaic residential generation. The trigger for migration is when the Community investor agrees to purchase a residential photovoltaic system, and simultaneously the Utility agrees to incorporate the resultant revenue offset into their generation profile under the net-metering concept. If these two requirements of cooperation are transparently and objectively managed, incremental generation shift has effect on resource sustainability, and offers benefit to each player toward mutually positive limits of this innovation adoption.

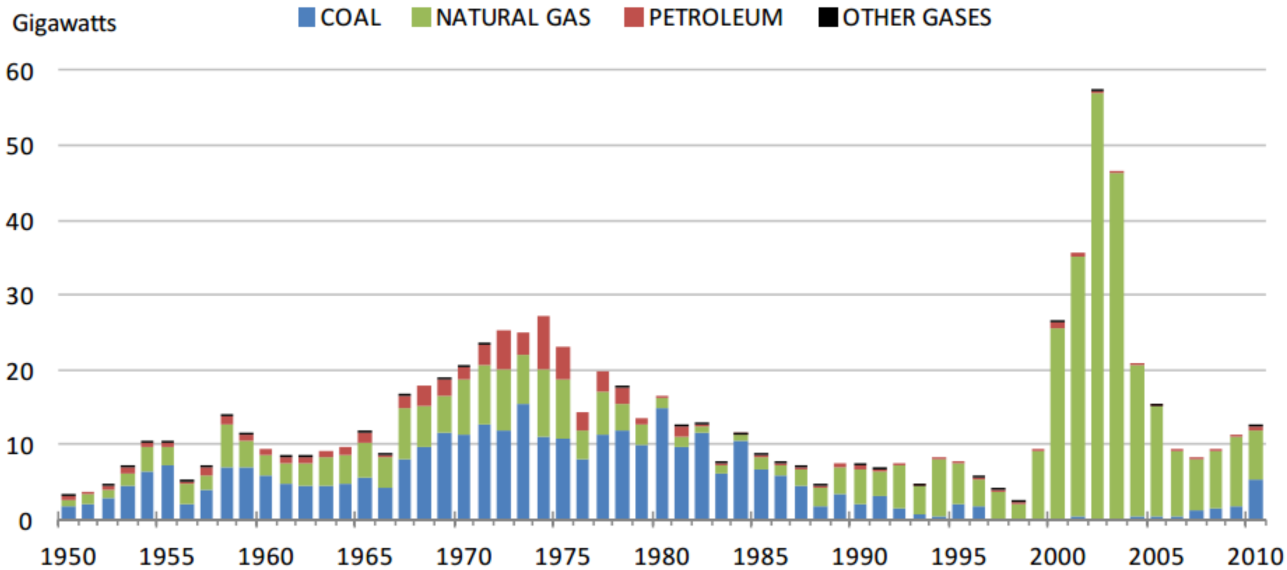
These concepts manifest themselves in specific actions typically enabled by Utility participation. First, the Utility must be willing to establish a desired level of residential adoption and generation positioning to benefit from community investment based on operational performance. Peak generation offset levels were estimated throughout section 3.2, and are used to define the sustainable adoption levels possible to enable a mutually beneficial scenario. Consider that if the Utility is able and willing to establish desired distributed generation detail and financial support for the Community to use for maximized adoption impact, a more sustainable generation profile can be achieved that benefits both players. Further, transparent Utility involvement enables more specific adoption models supported by a

single, respected data provider which is the Utility. Under this scenario, more clear environmental impacts can also be secured.

Utility willingness to publish registered grid-tied photovoltaic installation progress stimulates Community awareness and the marketing prowess of solar system installers. This information is reviewed in the Adoption section 3.7. Finally, Utilities and Communities, as players with a clear understanding of viable adoption levels for mutual benefit, will be better enabled to foster infant market development through policy and subsidy strategy that most rapidly achieves critical mass adoption (Rogers 2003). The following development within this cooperative assessment expands on specific research elements and data to understand the importance of an engaging relationship between the Community and Utility players.

The Natural Gas Generation Market as a Baseline

Natural gas fired generation technology is widely accepted as the current technology of choice for peak demand generation, and is supported by several factors. Most significantly, competitive retrofit and addition of natural gas as a primary fuel grows advantages of rapid startup and shut down times. In fact, industry experts estimate that a pairing of natural gas peaking units with renewable energy can satisfy generation fluxuation. In a recent repor,t Partnering Natural Gas And Renewables In ERCOT from The Brattle Group, they indicate that photovoltaic installations will "displace some gas-fired generation (either existing or new) since solar PV generates substantial amounts of power on-peak, when generally gas-fired power generation sources are producing energy at the margin." (Fox-Penner 2013). The U.S. Energy Information Administration also provides data to support this trend, which indicates that recent generation profiles resoundingly support gas-fired additions over other fuel types, as illustrated in the following figure 3.4.1:



Source: U.S. Energy Information Administration, Form EIA-860, "Annual Electric Generator Report," for 2002-2010. Values for 1950-2001 were calculated using the operating (start) years listed in the Form EIA-860 report for 2002. Capacity additions for any plants that may have retired prior to 2002 are not included in this figure.

Figure 3.4.1: Fossil Fuel Net Summer Capacity Additions (All Sectors) (EIA 2013d)

Migration to gas fired power plants is evident through this data, which is also observed with the following United States Energy Information Administration report confirming that for the first time in the history of the United States fossil fuel consumption of coal and natural gas are competitive and nearly equal in the delivery marketplace (EIA 2013e)`.

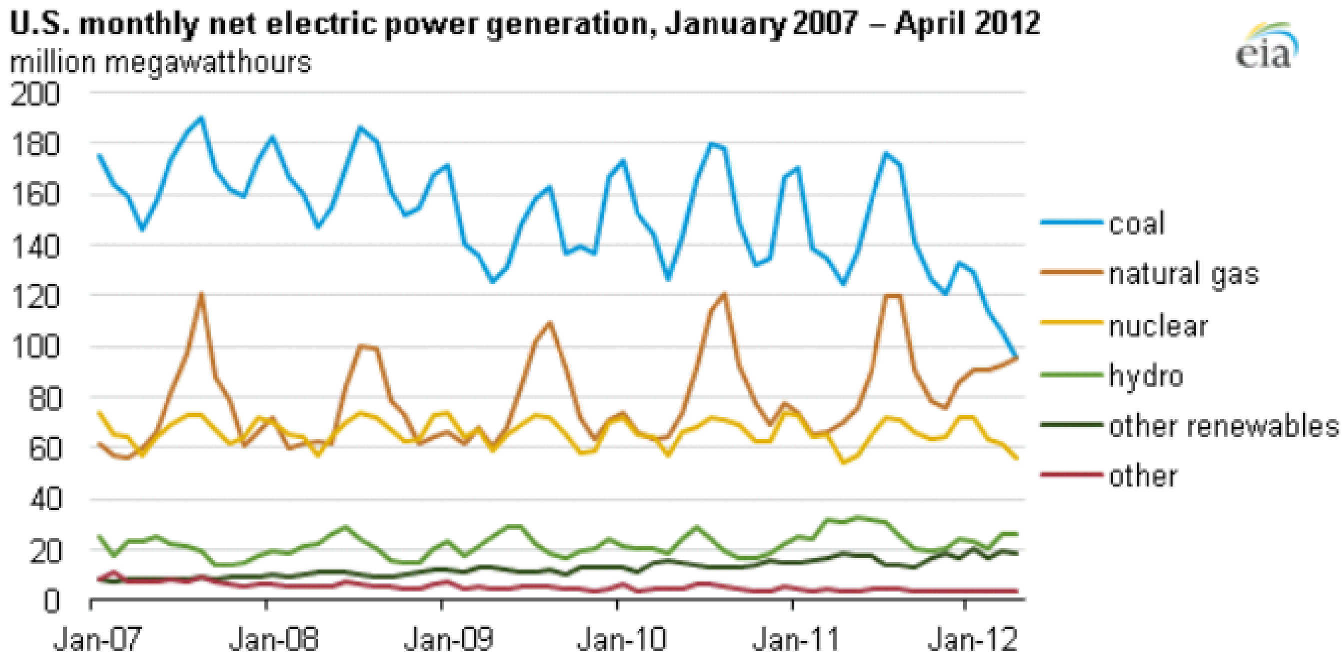


Figure 3.4.2: Monthly coal- and natural gas-fired generation equal for the first time in April 2012 (EIA 2013e).

Considering the observed technology migration to more natural gas generation, case study analysis and comparisons will use gas fired electricity generation as a benchmark for adoption comparisons. National data are also supported by Utility reports that demonstrate continued adoption of gas fired generation over other technologies.

APS, offers a summary of their 2012 generation profile in the following figure from their Base Case Portfolio - Energy Mix report:

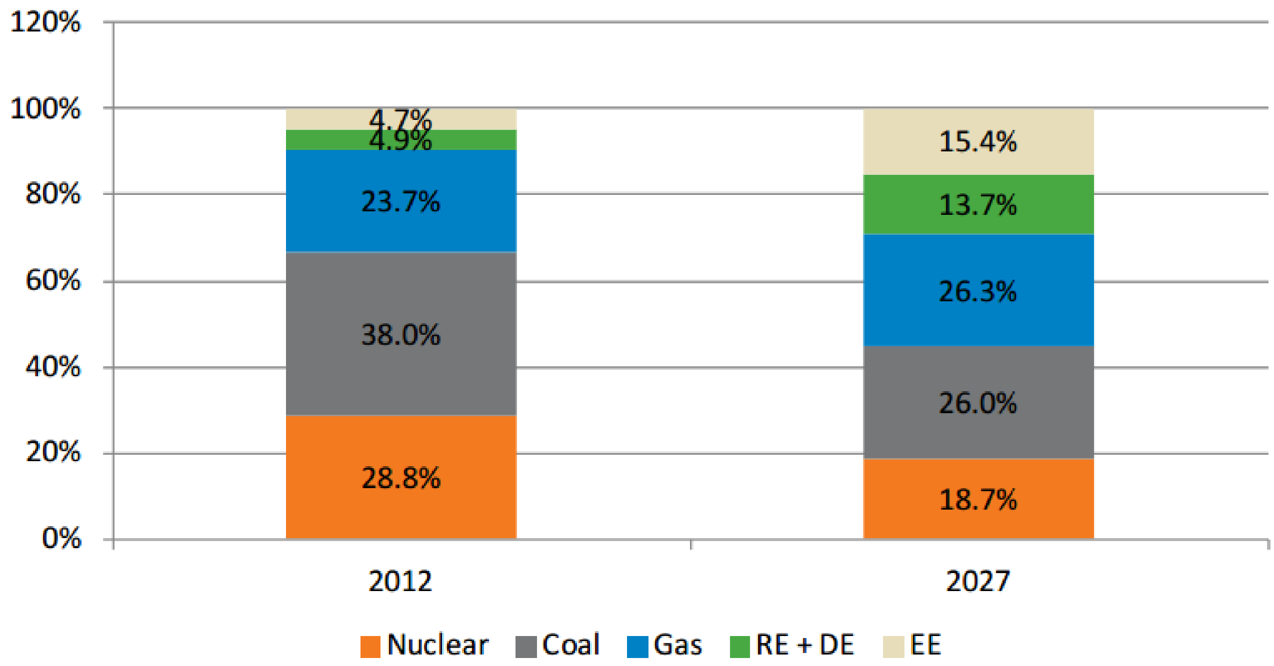


Figure 3.4.3: Arizona Public Service, Base Case Portfolio - Energy Mix (APS 2013)

Portland General Electric (PGE) offers similar generation profile information on their website, which is reproduced below:

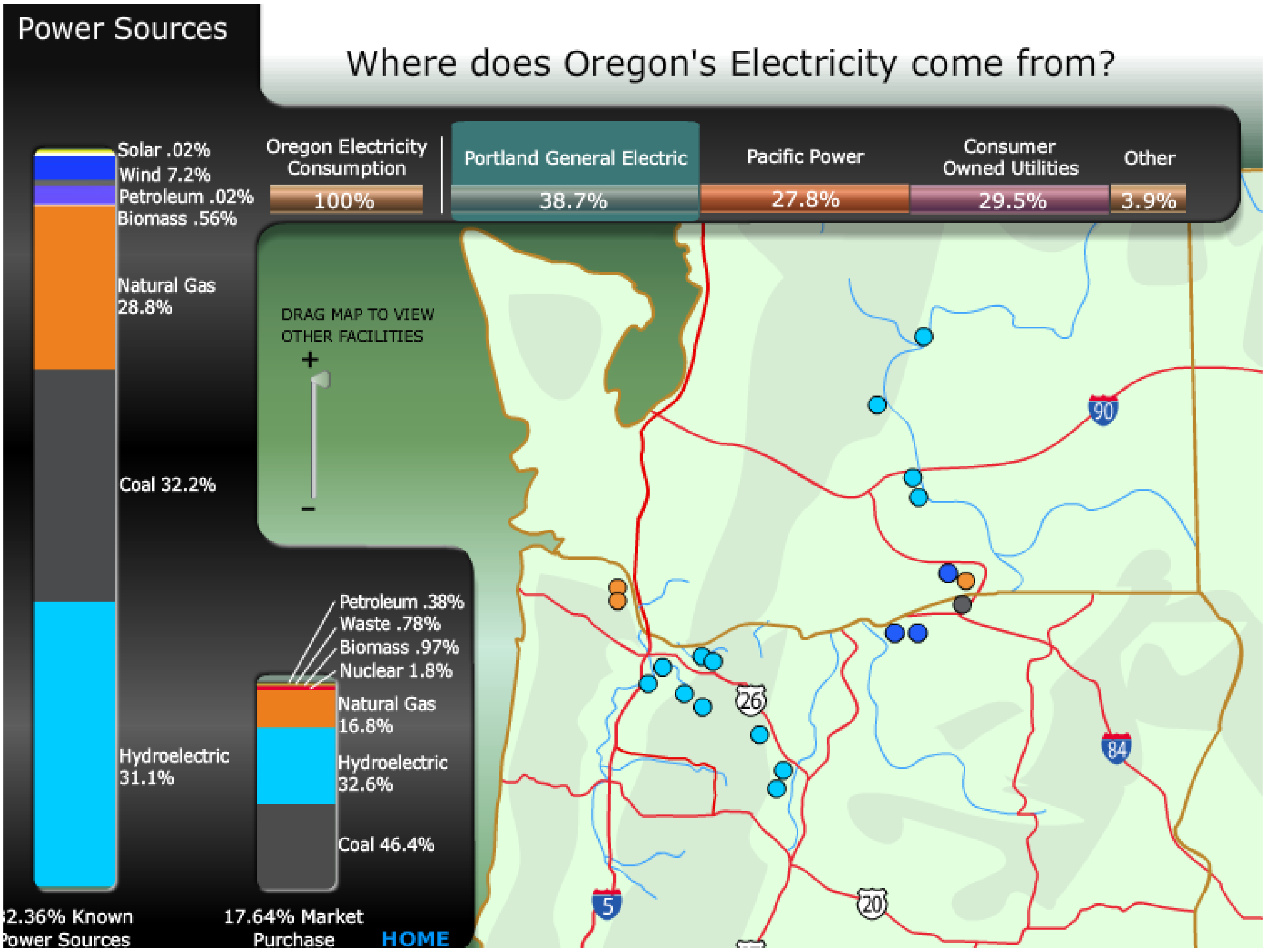


Figure 3.4.4: Portland General Electric - Where does Oregon's Electricity come from? Power Sources. (PGE 2013a)

The generation profile for El Paso Electric was presented earlier in the demand section, and was shown to be in excess of 50% gas fired generation. Based on these data, this study assumes that targeted peak demand is addressed by fast startup or peaking units that operate using natural gas as analyzed by Brattle (2012). Each of the Utilities considered in the case studies have a minimum of 23.7% use of these types of generation units as witnessed for APS at the low range, to over 50% gas fired units as observed with El Paso Electric's portfolio. Natural gas generation is then proven to be the principal competition to photovoltaic introduction primarily on a simple cost basis, but also can be used to understand the auxiliary impacts to Quality of Life for a given Community..

Air Quality Impact of Residential Photovoltaic Adoption

The first cooperative environmental category for assessment is air quality impact of residential photovoltaic adoption as compared to centralized generation.

Case study comparisons are dependent on current state and the anticipated generation offset allowed by incorporation of this renewable technology to the levels in the generation portfolio prescribed in section 3.2. The Environmental Protection Agency (EPA) continuously assesses air quality indicators for the test case cities. Their findings are summarized by a non-profit agency called Find the Data, and the following table was created from a query within the Find the Data assessment toolset that compiles air quality metrics based on the most recent, available information from the EPA. These results are provided in table 3.4.1:

Table 3.4.1: Air Quality Statistics (Find the Data 2013)

Now Comparing	Maricopa County, Arizona Air Quality	Multnomah County, Oregon Air Quality	El Paso County, Texas Air Quality
	SEE DETAILS ›	SEE DETAILS ›	SEE DETAILS ›
Air Quality Smart Rating			
Smart Rating	57	75	80
Key Air Quality Stats			
Carbon monoxide (ppm)	3	2	4
Nitrogen dioxide (ppm)	0.025	0.01	0.016
Ozone (ppm)	0.073	0.061	0.072
Lead (µg/m^3)	—	—	0.04
Particulate matter 2.5 (µg/m^3)	35	22	41
Particulate matter 2.5 WTD (µg/m^3)	11	7.6	8.4
Particulate matter (µg/m^3)	400	43	90
Sulfur dioxide AM (ppm)	0.002	0.002	0.001
Sulfur dioxide (ppm)	0.004	0.004	0.004

Details of their study can be found at their website included in the references section. As is shown, the overall air quality or 'Smart' rating provides both the Community and the Utility with information regarding the urgency of air quality concerns for each of the case study cities. As shown in the table above Phoenix, located in Maricopa County, ranks the lowest with a Smart score of 57. Portland and El Paso have relatively similar air quality performance with scores of 75 and 80 respectively.

With natural gas defined as the offset technology, this study can now evaluate emission level reduction residential grid-tied photovoltaic installation as a contributor to localized air quality. The U.S.

Energy Information Administration publishes average emission levels for gas fired generation, which were summarized in a recent installation plan by El Paso Electric and published in a disclosure for future generation and grid development. The following table 3.4.2 summarizes the anticipated emissions for gas fired General Electric turbines planned for installation to support El Paso Electric expansion in the Montana Vista neighborhood in El Paso:

Table 3.4.2: Fossil Fuel Emission Levels (EPE 2012, p. 10)

Pounds per Billion Btu of Energy Input

Pollutant	Natural Gas	Oil	Coal
Nitrogen Oxides	92	448	457
Sulfur Dioxide	1	1,122	2,591
Particulates	7	84	2,744
Mercury	0.000	0.007	0.016
Carbon Monoxide	40	33	208
Carbon Dioxide	117,000	164,000	208,000

With these emissions data, this study now considers how air quality is affected by offsetting current gas fired peak generation emissions performance using residential photovoltaic generation on a unit basis. The above emission values provided by the U.S. EIA are used to provide emission offset based on residential grid-tied photovoltaic installation for each of the case studies.

Applying the conversion of 1 kilowatt hour equals 3,412.141 479 9 Btu and 1 kilogram is equal to 2.204 pounds, the above table can be converted into kilograms of emissions per kilowatt hour of electricity generated. As natural gas is assumed to be the technology offset for PV the following kilowatt hour production emission conversion table can be calculated:

Table 3.4.3: Fossil Fuel Emission Levels Converted to SI Units

	Fossil Fuel Emission Levels (Kilograms per kilowatt-hour)		
Pollutant	Natural Gas	Oil	Coal
Nitrogen Oxides	0.000142431	0.000693575	0.000707509
Sulfur Dioxide	1.54816E-06	0.001737034	0.004011279
Particulates	1.08371E-05	0.000130045	0.004248148
Mercury	0	1.08371E-08	2.47705E-08
Carbon Monoxide	6.19264E-05	5.10892E-05	0.000322017
Carbon Dioxide	0.18113458	0.253898044	0.322017031

Emissions data are summarized at the end of the Methods section to understand air quality impact Community investment in PV offers.

Water Consumption Impacts

Similar to the directional estimates for emissions, water consumption is also an important factor regarding the of peak electricity generation using distributed residential photovoltaic technology to offset natural gas fired approaches. As with emissions, specific information for each case study is not directly available from the Utilities and this research presents average estimates expected with distributed residential photovoltaic technology adoption.

The principle data source used for this analysis will be the U.S. Department of Energy report Energy Demands On Water Resources, Report To Congress On The Interdependency Of Energy And Water, issued December, 2006. An assumption is made that natural gas generation using a closed loop system is applied as a conservative estimate, although hybrid systems are in use. Often public concern over resource use motivates the Utilities to ensure that water consumption is minimized and that open loop systems that influence waterways are reduced to the extent possible.

Table 3.4.4: Energy Demands On Water Resources; Report To Congress On The Interdependency Of Energy And Water (DOE 2006)

		Water intensity (gal/MWh$_e$)			
Plant-type	**Process**	**Steam Condensing**		**Other Use**	
Steam		**Withdrawal**	**Consumption**	**Withdrawal**	**Consumption**
Fossil/ biomass/ waste	OL Cooling	20,000–50,000	~300	~30**	
	CL Tower	300–600	300–480		
	CL Pond	500–600	~480		
	Dry	0	0		
Nuclear	OL Cooling	25,000–60,000	~400	~30**	
Nuclear	CL Tower	500–1,100	400–720		
Nuclear	CL Pond	800–1,100	~720		
Nuclear	Dry	0	0		
Geothermal Steam	CL Tower	~2000	~1400	Not available	
Solar trough	CL Tower	760–920	760–920	8	
Solar tower	CL Tower	~750	~750	8	
Other					
Natural Gas CC	OL Cooling	7,500–20,000	100	7–10**	
	CL Tower	~230	~180		
	Dry	0	0		
Coal IGCC*	CL Tower	~250	~200	7–10 + 130 (process water)	

OL = Open loop cooling, CL = Closed Loop Cooling, CC = Combined Cycle
*IGCC = Integrated Gasification Combined-Cycle, includes gasification process water
Other Use includes water for other cooling loads such as gas turbines, equipment washing, emission treatment, restrooms, etc.
** References did not specify whether values are for withdrawal or consumption.

Investigation confirms that two types of gas fired units are in use for each of the case study entities: Natural Gas Combustion, and Natural Gas Combined Cycle. APS and El Paso Electric operate facilities with a blend (West Phoenix and Newman), with the remainder of all case study gas fired

production utilizing combustion or combined cycle processes. By applying the above DOE data for a weighted average based on production, directional estimates for each Utility can be made regarding locality water consumption per kilowatt hour of electricity consumed.

Table 3.4.5: Estimated Water Consumption of Test Case Natural Gas Fired Generation

Utility	Plant	Type of Gas Fired Units	Capacity (MW)	Assumed Average Water Consumption (gal/MWh_e)	Weighted Average Water Consumption (gal/MWh_e)	Data Source(s)
Arizona Public Service	Redhawk	Combined Cycle; Closed Loop	1060	190	268	(APS 2013a)
Arizona Public Service	West Phoenix	Combustion and Combined Cycle; Closed Loop	1000	(190 + 510)/2 or 350		
El Paso Electric	Newman	Combustion and Combined Cycle; Closed Loop	732	(190 + 510)/2 or 350	396	(EPE 2013a) (Reuters 2013)
El Paso Electric	Rio Grande	Combustion; Closed Loop	229	510		
El Paso Electric	Copper	Combustion; Closed Loop	62	510		
Portland General Electric	Beaver	Combined Cycle; Closed Loop	516	190	190	(PGE 2013b) (PGE 2013c)
Portland General Electric	Coyote Springs	Combined Cycle; Closed Loop	231	190		
Portland General Electric	Port Westward	Combined Cycle; Closed Loop	410	190		

When community offset contributions are multiplied by the factors included in the above water consumption table, an estimated water impact for each case study entity can be calculated and are presented in the summary table at the end of this Methods section.

Maintaining Capital within a Community

Community investment in residential grid-tied PV generation capacity can localize installation and operational benefits immediately to foster prosperity. Under centralized Utility based operation in the case studies, corporate ownership applies revenues paid by customers and channels them to investors that may not reside in the test case communities. Locally sourced and installed photovoltaic systems engage a wide array of materials and balance of system costs that help stimulate the local economies. Several studies and observations are available help define this impact, which is estimated to be 30% of the system investment.

An initial source to understand the local contribution of residential photovoltaic installation is offered by the Berkley Laboratories, which is reproduced in the following figure 3.4.5:

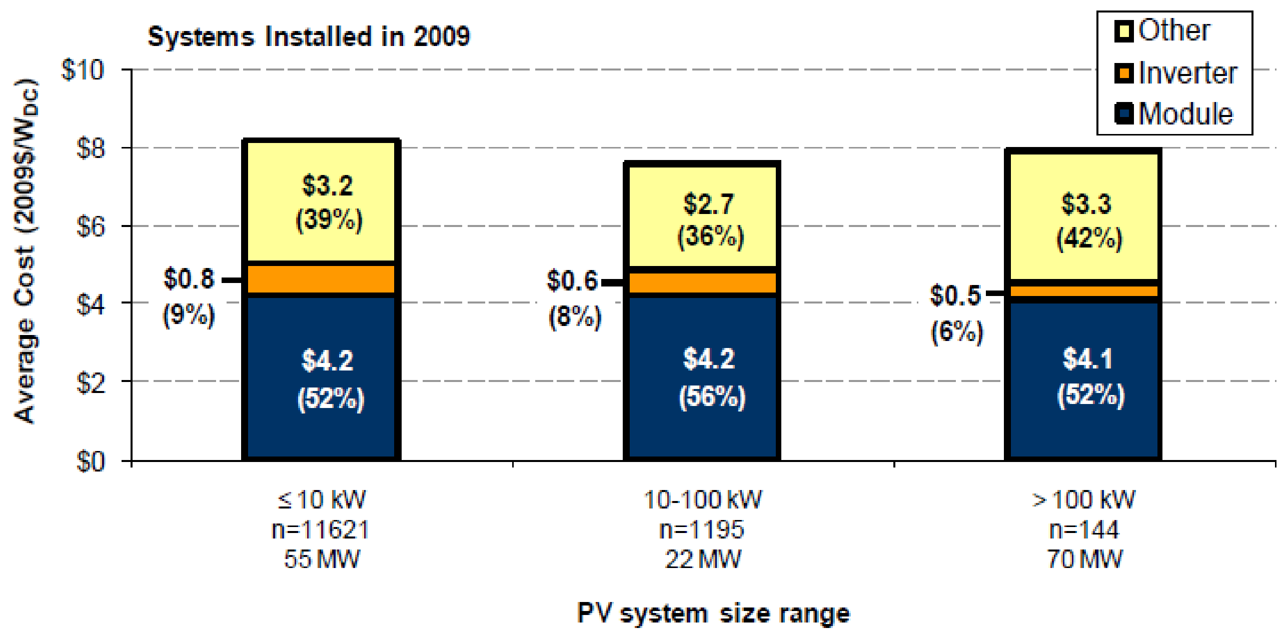


Figure 3.4.5: Module, Inverter, and Other Costs - Systems Installed in 2009. (Berkley Laboratories 2009b, p. 17)

As illustrated above, as of 2009 residential systems less than 10 kW have 39% of the cost structure engaged in the 'other' category. This provides a general sense of the amount of labor involved with a photovoltaic system installation, albeit some element of those funds are dedicated to hardware required for the installation. While this cost component is largely driven by labor, an assumption is made that some element of this pricing component is involved with wiring, conduit, connectors, and the remainder is driven by labor content associated with installation. A study provided by Wiser et al. in the same year, further breaks down these high level numbers provided in the Berkeley study:

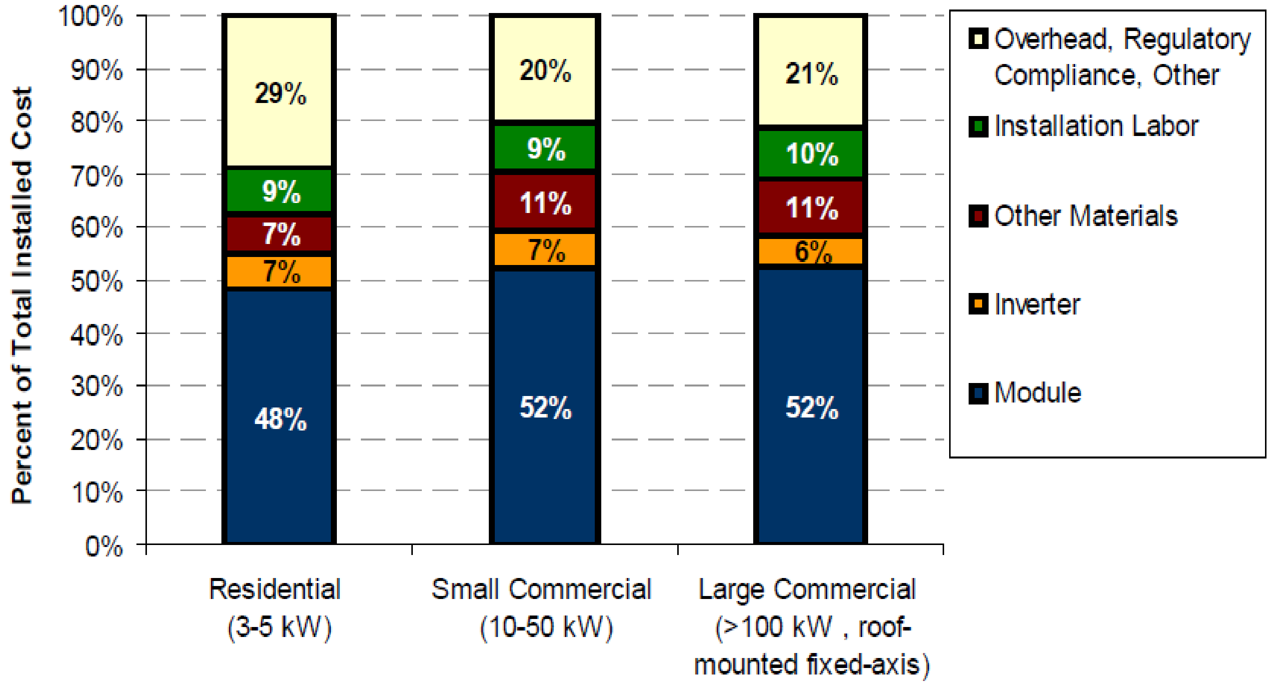


Figure 3.4.6: PV installer data on component costs (Berkley Laboratories 2009b, p. 81)

The Wiser study indicates that fully 38% of system installation cost is driven by overhead, regulatory compliance, installation labor, and general materials as main factors among others. As a directional indicator, a conservative estimate of 30% of installation cost is assumed directly related to local economic contribution and remains within the Community (assuming local sourcing).

Two additional steps were taken to validate the assumption that 30% of residential photovoltaic investment immediately contributes to the local economy. A detailed assessment provided by the Interstate Renewable Energy Council (IREC) that further adds transparency to the claim of 30% directly local content of residential solar installations. These are data is reproduced in the following figure 3.4.7:

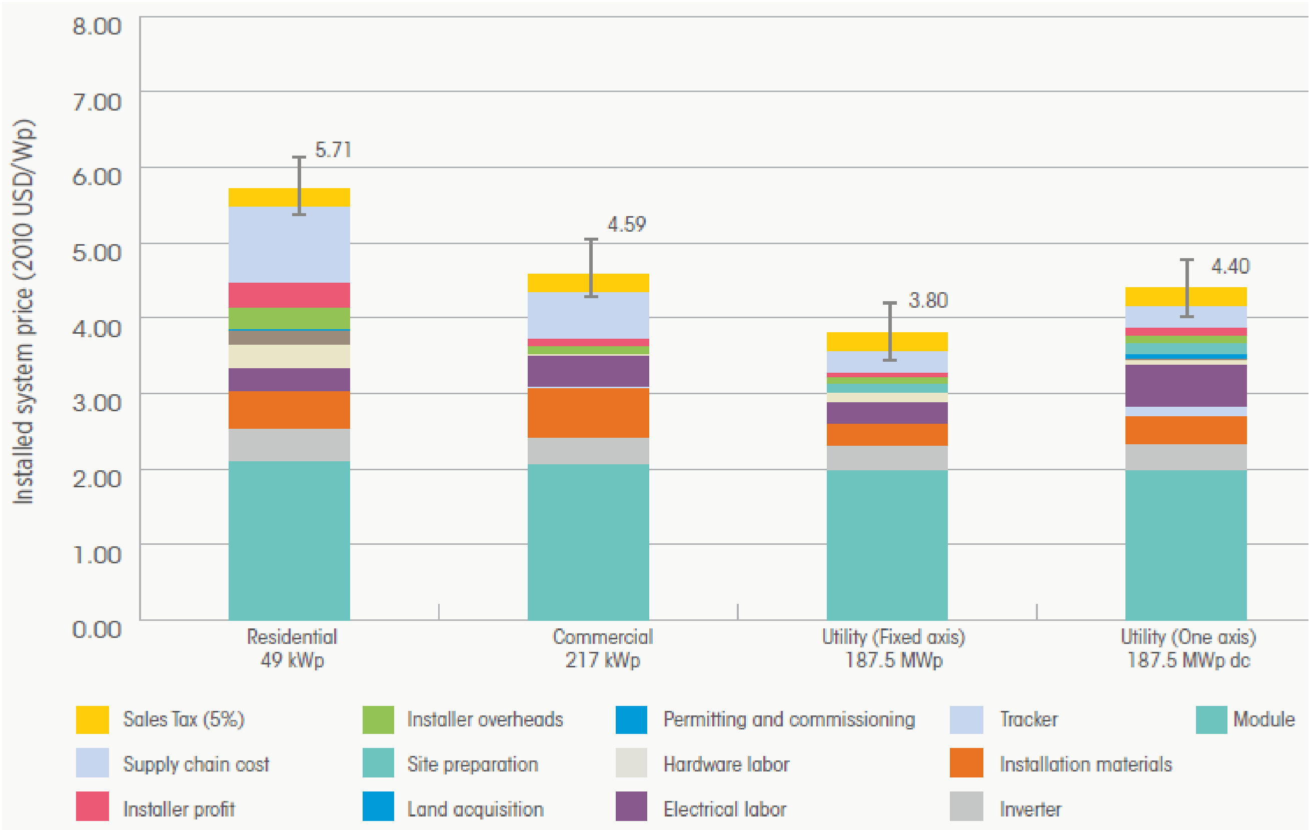


Figure 3.4.7: System Cost Breakdown for Residential, Commercial, and Utility-Scale c-Si systems in the United States 2010 (IREC 2012, p. 25)

As indicated in the prior studies and also observed in the IREC data, approximately 30% of installation costs can be directly integrated into the local economy through labor for residential systems. These expenses for initial installation direct a significant portion of initial PV investment directly into local community economies. Contributions can then foster economic growth by promoting cash flows that would otherwise be driven out of the system boundary through corporate finance. In this sense, residential photovoltaic installations present a 'plowback' of investment opportunity to the local Community.

Finally, national statistics are reinforced by an interview with Mr. Oscar Martinez, a local installer in the El Paso area. He supported these public domain data claims by confirming that 30% of labor cost buildup of solar installations can be attributed to local cost elements. Clearly, residential grid-

tied photovoltaic installation can enable a Community to preserve cash locally while contributing to local sustainability strategy if financially viable. As was demonstrated by the works of Ostrom (1990), localized considerations and decision-making can lead to more beneficial Community outcomes.

Increase of Community Disposable Income

Community disposable income can be created through more beneficial electricity investment that improves economic performance by yielding a higher net present value over current state. As production options are considered, due diligence must be exercised to ensure that investment provides anticipated returns. These returns above status quo define additional disposable income available through the resource decision-making process and can positively affect Community prosperity.

Disposable income is recognized in the Community as improved investment return beyond the current centralized model, which is the comparative baseline in this research. The financial models in section 3.1 support that individual Community members are offered a decision: Do they become participant generators with residential PV, or continue with the status quo? Between the two alternatives, game players must consider where personal values reside, and place a myriad of values against the financial implication of making change. The following table summarizes the presented levels of investment return for community members that (1) accept current pricing models based on risk versus return criteria for their respective local markets and (2) decide to invest in an average solar system:

Table 3.4.6: Locality Disposable Income Change as a Percent of Investment Over Status Quo

Locality	Estimated Current Installation Market Price ($/W)	Estimated System Size (PVWatts, kW)	Federally Published State Retail Unit Rate ($USD/kWh)	Calculated Annual System Generation (kWh)	Calculated Investment Rate of Return (IRR) at Market Price
El Paso	$ 3.50	4.7	$ 0.1106	7788	5.7%
Phoenix	$ 5.20	4.82	$ 0.1036	7788	0.9%
Portland	$ 6.00	7.65	$ 0.0977	7788	-5.2%

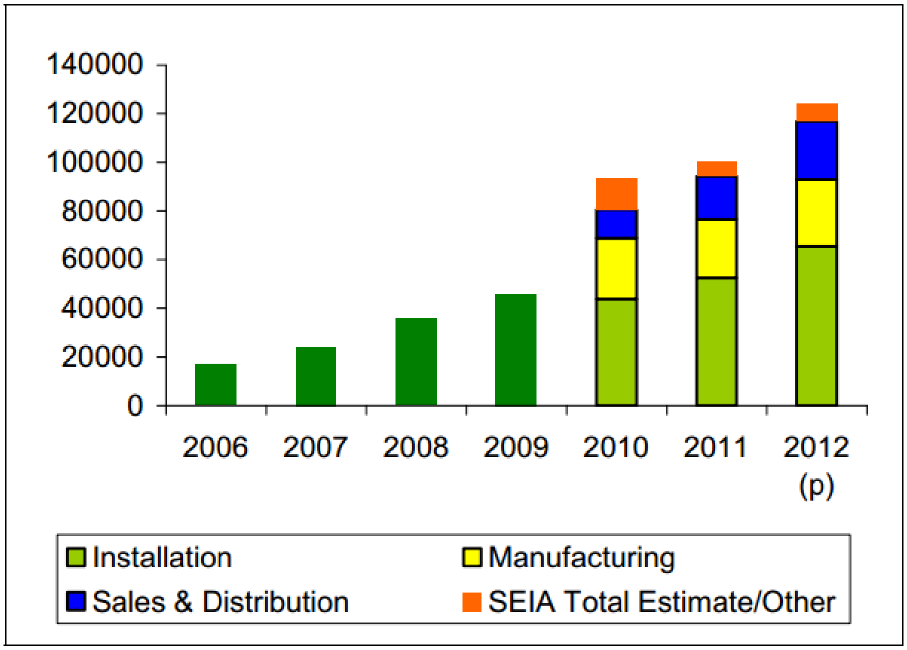
As quantified above, not all case study Communities benefit financially from the addition of residential grid-tied photovoltaic installations. Investor disposable income is driven by net benefit over

the status quo based on anticipated value of the investment. Currently, in the El Paso and Phoenix markets a relatively small opportunity to (1) invest and (2) recognize benefits exists as a positive return on investment at 5.7% and 1.0% respectively. This implies increased availability of disposable income over the status quo as adopters would recognize lower net present value electricity, and could dedicate investment gain toward other local growth actions. Solar insulation and market price points in those two case study markets allow for current electricity consumers to benefit from adoption.

In the Portland case, market pricing relative to investment return is not beneficial. Stated alternatively, a residential PV system at market installation price points, geographic performance, and defined assumptions actually destroys economic value, and Portland Community members have a more sustainable financial solution by remaining with the centralized generation scheme offered by Portland General Electric.

Local Job Creation, Workforce Development, and Manufacturing

Job creation is a challenging metric to develop on a city specific level, but plays an important role when considering the true sustainability of migration to residential PV. As was defined in the previous "Maintaining Capital within a Community" sub-section, an estimated 30% of the initial investment remains in a Community if installed by locally based providers. These employment elements take various forms that can be summarized under the following general job descriptions as presented by (Plantzer 2013):



Source: SEIA, National Solar Job Census, 2011. 2012 data are preliminary.

Notes: Other refers to project development, R&D, and finance. From 2006 to 2009, SEIA estimated the number of jobs and did not conduct a census for those years.

Figure 3.4.8: Domestic Solar Industry Employment Trends 2006-2012 (Plantzer 2013, p. 15)

Major job creation categories can be further defined as referenced in the above figure to better understand national photovoltaic driven employment trends as they apply to local sustainability efforts:

- Installers: Distributed, small scale residential PV expansion most significantly can drive local community job growth through installers. As localized PV systems are smaller scale installations, economics dictate that installation can efficiently operate with locally owned and operated providers, with the assumption they can access national equipment manufacturers and distributors at competitive pricing. Note that as a response to installer demand, national providers may establish city specific r installation and marketing capabilities, and leverage economy of scale by centralizing purchasing / manufacturing nationally (even internationally) by operating local offices.

- Support Functions (Sales, Marketing, Administrative, Logistics, Construction, etc.): In larger markets Sales, General, and Administrative functions can grow when installer operation necessitates more support. Management roles such as project planning and administration can generate community employment. Warehousing and transportation services may also be required to accommodate a growing residential PV industry as examples of supporting functions.
- Manufacturing: Each case study Community currently experiences manufacturing footprint development of system components. As examples, El Paso claims development with Sun Edison in partnership with Foxconn Technology Group; Phoenix has an established manufacturer with First Solar; and, Portland also can claim localized manufacturing with SolarWorld located on the outskirts of the city in Hillsboro, Oregon.

Employment opportunities exist throughout the sustainability value chain, and each of the test case localities are affected by residential photovoltaic adoption. As with any large scale industry, a choreographed series of needs must be addressed. In the case of solar, the Interstate Renewable Energy Council (IREC) reviewed employment opportunities and economic contributions as related to each other to expand on the observations presented above from SEIA. An example of of the IREC employment assessment is reproduced in the following figure:

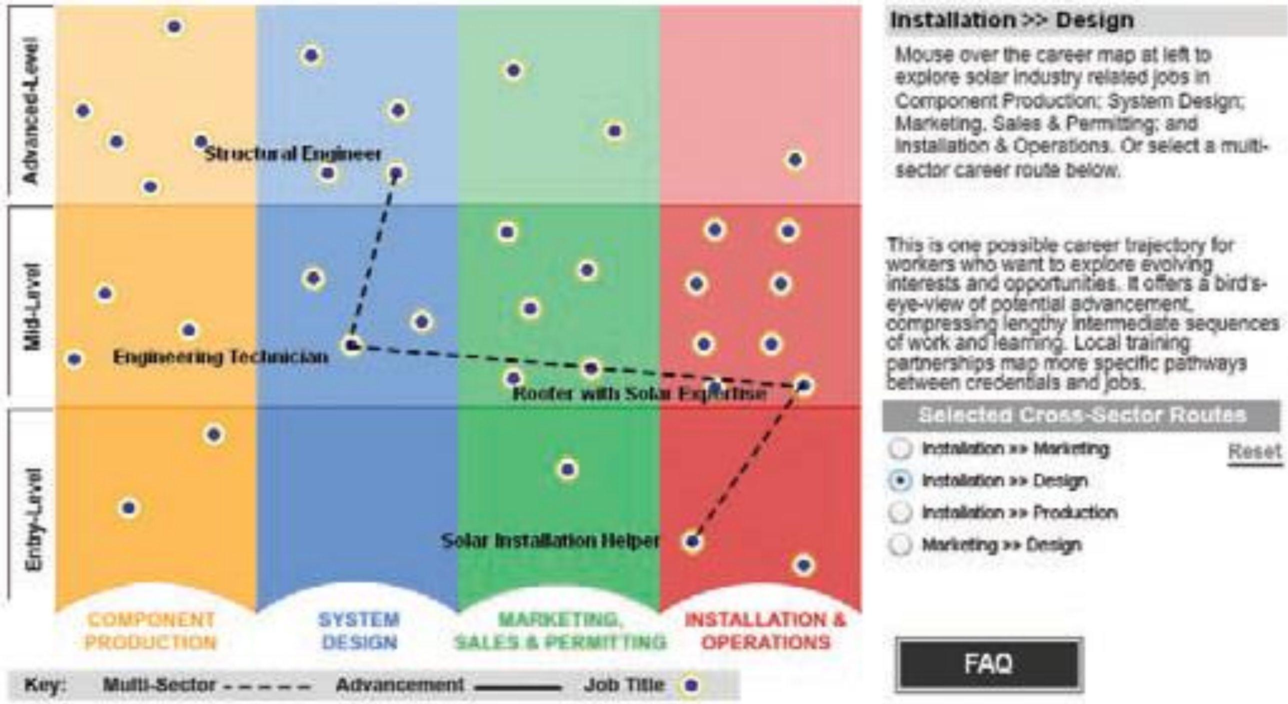


Figure 3.4.9: 2012 Annual Updates & Trends Report, Solar Career Map (IREC 2012, p. 29)

IREC employment estimates are also supported in a solar industry employment report presented to U.S. Congress by Michaela Platzer in 2012. In her report she summarizes that "the solar manufacturing sector supported about 25,000 jobs nationwide in 2011. This accounted for only about one-fourth of U.S. employment related to the solar energy sector. The remaining 75% of the 100,000 full-time workers employed directly in the solar power industry as of August 2011 are involved in other segments of the industry, including installation, sales and distribution, project development, research and development, and finance." (Plantzer 2013)

When this emerging PV industry is viewed at a national level, it is relevant that the Bureau of Labor Statistics (BLS) does not track employment data for the solar power industry to date. Plantzer reported that the Census also includes jobs not directly related to PV, such as manufacturing of solar water heating systems. To address the shortfall in employment data related to the 'green' economy, the Bureau of Labor Statistics (BLS) has undertaken a "green jobs" initiative to measure jobs at establishments that produce 'green' goods and services and use environmentally friendly production

processes and practices. Initial data collection efforts are underway, and include the recent release of employment data on green goods and services which can be viewed online (The Solar Foundation 2013).

A final job creation category worthy of mention is education. As demand grows, installers become higher in demand, and support functions expand. These expansions present industry growth which increases demand for trained individuals for these roles. Educational institutions ranging from high school, trade schools, junior colleges, and universities are tasked to deliver these industry experts, and present another category of Community prosperity growth. True impact in terms of employment is difficult to determine, but additional roles through education services are influential as direct labor must be trained, certified, and capable to deliver supported products and services. This topic is expanded in the Educational Impacts sub-section to follow.

Financing and External Capital Infusion

Ideally, residential photovoltaic investments are housed within the local community to clearly account for contributions. Unfortunately, exact financing and external capital infusion data are challenging to quantify as national entities regularly fund PV investments and direct local contributions become difficult to quantify in terms of local sustainability impact of adoption. The challenge to enable sustainability analysis is to understand if these external financing options and returns are locally recognized help foster Community prosperity.

For this work, an assumption is made that investment capital is locally accessible, and that benefits from those investments remain in the Community. Sustainability assessment in these cases considers a 'closed' system where investment is evaluated strictly within local Community investment. Paramount to this Framework application is the assumption that the local Community harnesses and 'plows back' recognized costs for energy with the added benefit of supporting the local Community.

Educational Impacts toward Sustainable Electricity in the Community

Modern residential photovoltaic systems offer a platform to channel income to locally recognized benefits in Communities. As previously discussed, these benefits can be recognized through

enhanced Quality of Life margins for both the Community and Utilities in the form of reduced emissions, water consumption, and economic growth. This knowledge development in the Community is classified here as Educational Impact, and can be discussed on two different levels: The first level is the general education within the Community to promote energy efficiency and conservation; The second is education related to job creation through training to accommodate the actual proliferation of the renewable energy industry.

Beyond installation education investment in a residential grid-tied photovoltaic systems, installations promote energy conservation through knowledge and behavior communication that enable sustainability. Modern PV installations include monitoring tools operated through the grid, and can provide investors with real-time electricity generation and use data to identify efficiency and conservation decision-making opportunities.

As was presented by Arizona Public Service in their Integrated Resource Plan, energy efficiency is the most cost effective means to promote sustainability action from a cost perspective. Residential photovoltaic systems serve as a measurement tool and catalyst to promote homeownerbehavior modification and reduce their energy consumption. The following reproduction of APS comparative findings which illustrate a general technology comparison of decision-making options, reproduced in figure 3.4.10:

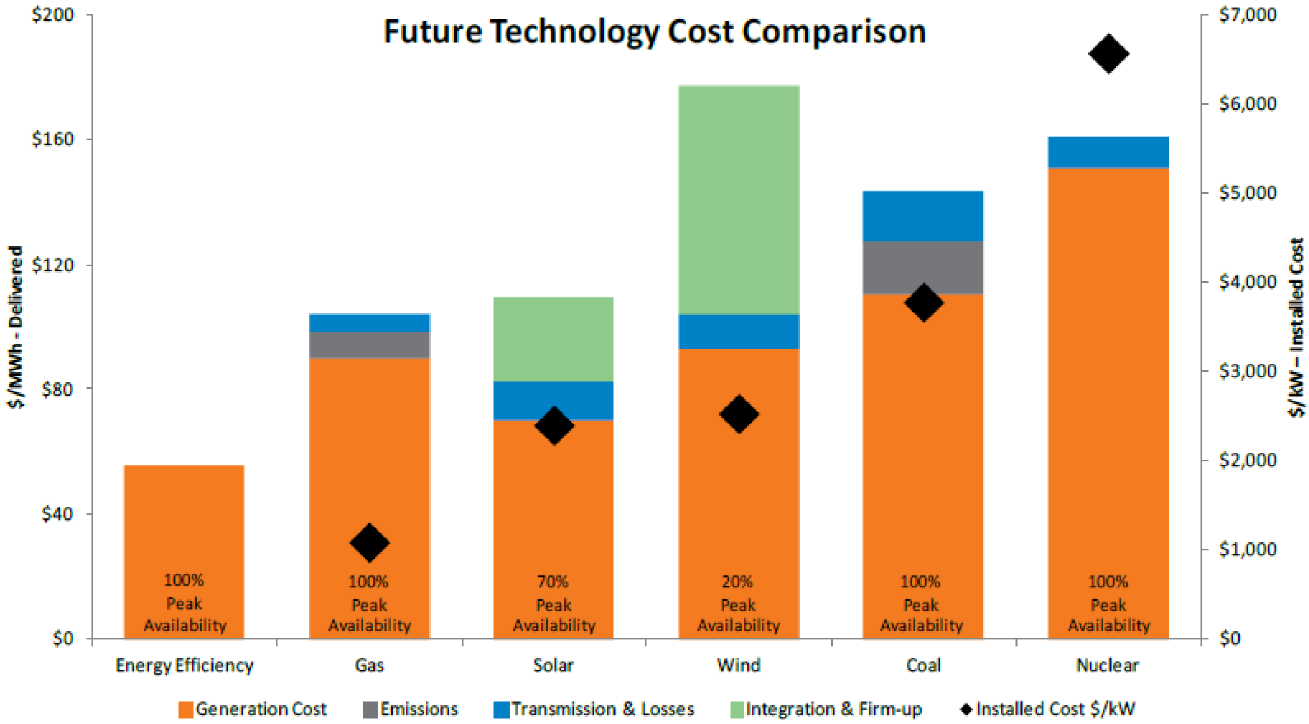


Figure 3.4.10: Technology Cost Comparison: Delivered Cost and Installed Cost (APS 2012, p. 31)

While residential grid-tied installations are only the third best contributor to energy sustainability per the APS data, these installations additionally offer measurement tools to assist the homeowner to understand efficiency gains available such as appliance usage timing to better offset peak electricity demand. The potential result of measurement tool usage is community educational advancement through more detailed exposure to electricity consumption and generation profiles as an educational element.

Based on the above APS data, efficiency investment offers the lowest barriers to entry and the most direct return on investment when compared to other renewable options. While Residential PV installations are a third best option, they not only provide renewable generation but also facilitate consumption measurement to identify specific efficiency gains thereby promoting efficiency education.

A case in point is the researchers personal involvement with the residential, grid-tied photovoltaic market in El Paso. As part of this research, a 2.4kW system was purchased in November,

2011 and came online in December of the same year. The following graphic provides a pictorial overview of the installation for reference in figure 3.4.11:

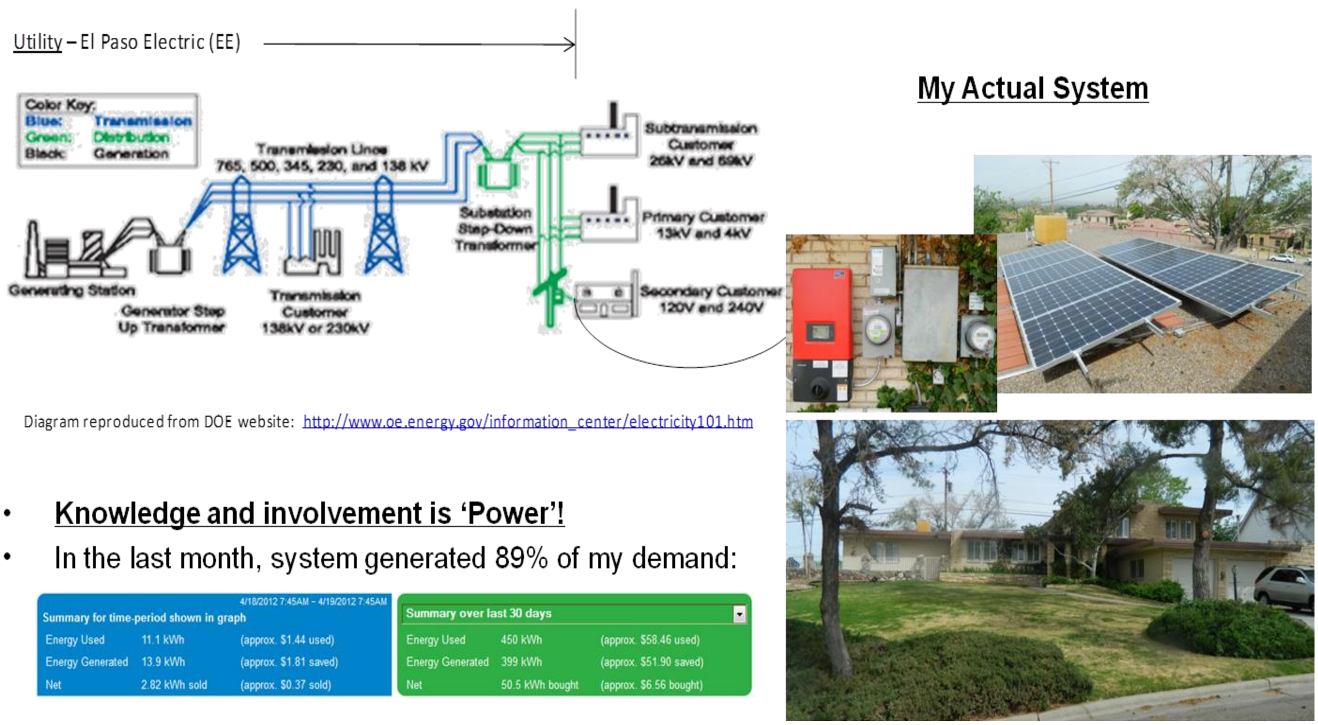


Figure 3.4.11: Researcher Residential System Connection Diagram and Efficiency (Cole 2012)

Residential grid-tied photovoltaic installations offer energy measurement capabilities through the power lines to enable more effective efficiency assessments. As stated in the above figure, "Knowledge and Involvement is 'Power'!" when made available to individuals willing to react to information available.

As part of this research, direct investment was made to gain firsthand experience with residential grid-tied photovoltaic systems. Installation has allowed the researcher to immediately assess electricity consumption and generation statistics. As common and part of the PV installation package, the 2.4kW system included eGauge is the monitoring tool to understand electricity flows from both generation and

consumption perspectives. The following figure 3.4.12 is a sample output from the eGuage tool which has been used to understand and modify family behavior through PV installation education:

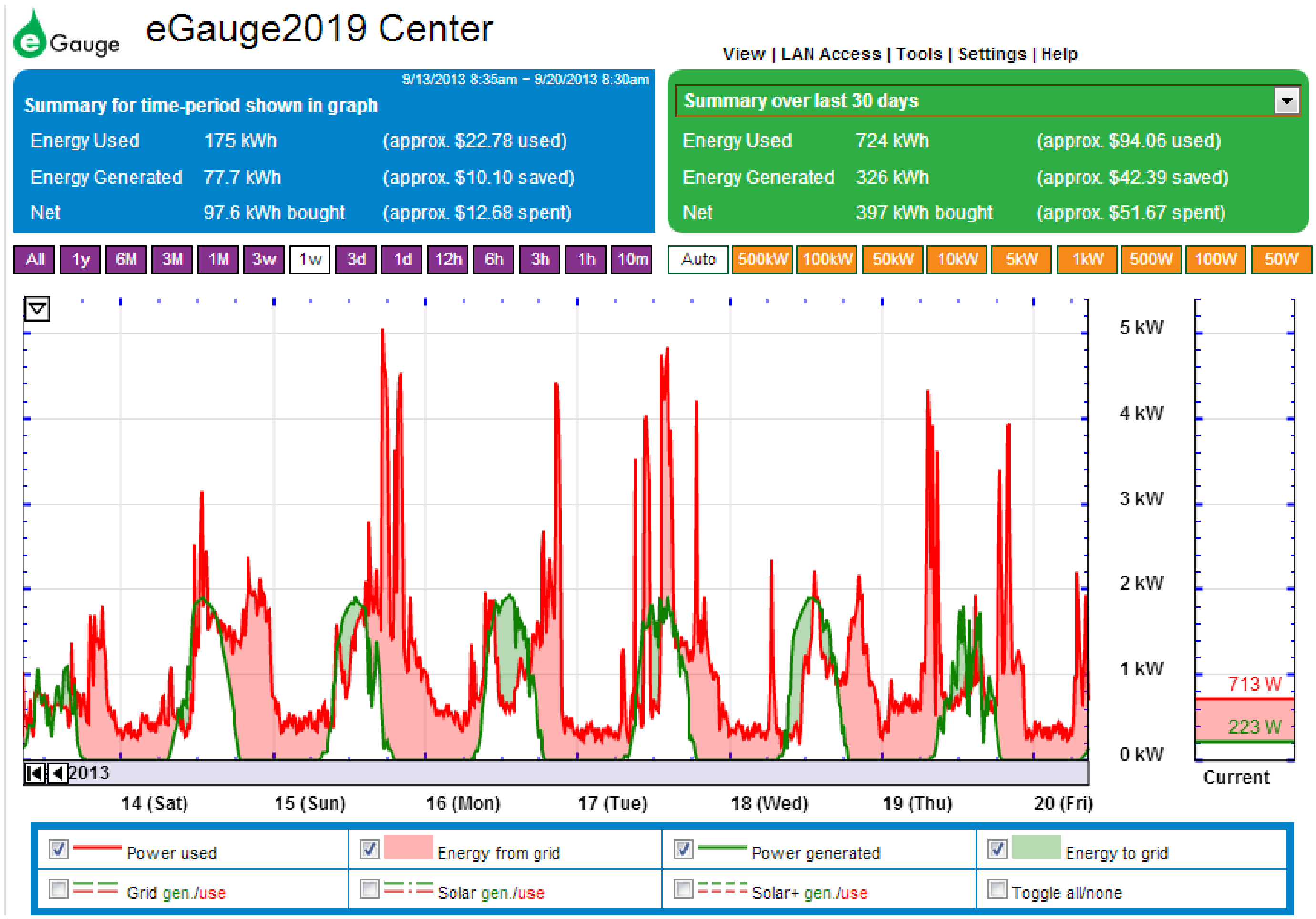


Figure 3.4.12: eGauge System Output to Illustrate Educational Elements (9/13/13 to 9/20/2013)

These PV system outputs are available for any time period since installation, and are helpful to understand how household operation impacts Community electricity use. For example, energy spikes indicated in red represent the electric clothes dryer operation; base consumption during evening hours represents air conditioning units and safety lighting. As conscious residential consumers, the household has been enabled through the residential PV system to push high consumption operations and devices

'off peak', and identify the impact of device conversion (LED lighting, for example) to create more sustainable electricity consumption.

This work reviews many factors that influence energy sustainability related to residential photovoltaic technology, yet can only expand on certain key elements relevant to ISDMF operation and only mention others as components. The above review of general Community education enabled by residential PV installations is more directly related to downstream effect, and is subject to uncertainty. For this reason, this educational factor based on Community engagement is only mentioned but not included in the summary as a defined Community action for ISDMF application.

Impact of Green City Reputation on Community Growth

Municipalities can benefit from progressive player contribution to sustainability. These actions afford opportunity to differentiate their Communities above others, and stimulate external investment based on local reputation. Direct impacts of this 'green' differentiation are beyond the scope of this study, but results are clear that recognition of Community action to promote sustainable resource management enhances progressive external investment (Citation needed).

Cooperative Action and Subsidies

Financial barriers have historically limited widespread residential photovoltaic adoption, and each test case city has responded by implementing financial subsidy strategies to promote this technology. Through their actions, test case municipalities recognize the importance of emerging technology promotion to foster adoption, and each has engaged subsidies as a catalyst to accelerate migration to varying levels of success.

As was demonstrated in an earlier Methods sub-section, installed system pricing trends lower over time due to manufacturing, distribution, and installation economy of scale in competition. In parallel, subsidy regimes are dynamic to reflect those pricing trends and have decreased over time as grid parity with other electricity generation and delivery technologies is approached. This is the point whensubsidies are no longer needed to stimulate adoption. Municipalities wishing to promote

photovoltaic adoption have to carefully monitor market pricing to ensure that they appropriately emphasize the infant technology but do not over-extend promotion at a Community financial loss.

Subsidy is Big Business, and the question arises if society gain when it is applied? Nationwide investments in both traditional and alternative technologies are serious concerns and Federal, state, and local regulatory bodies continuously establish efforts to secure more sustainable energy initiatives. They often infuse market altering promotion to accelerate the trajectories to ideal case solutions by applying the vehicle of subsidies. Subsidies decrease barriers to entry for investors and simultaneously promote infant strategies consumers desire. This is done with the expectation that these investments will result in longer term benefits by providing decreased cost of entry and research funding to enable viable fledgling technologies.

The U.S. dedicates significant capital to promote longer term gains, as is illustrated in the following summary of subsidy contributions for various energy delivery options:

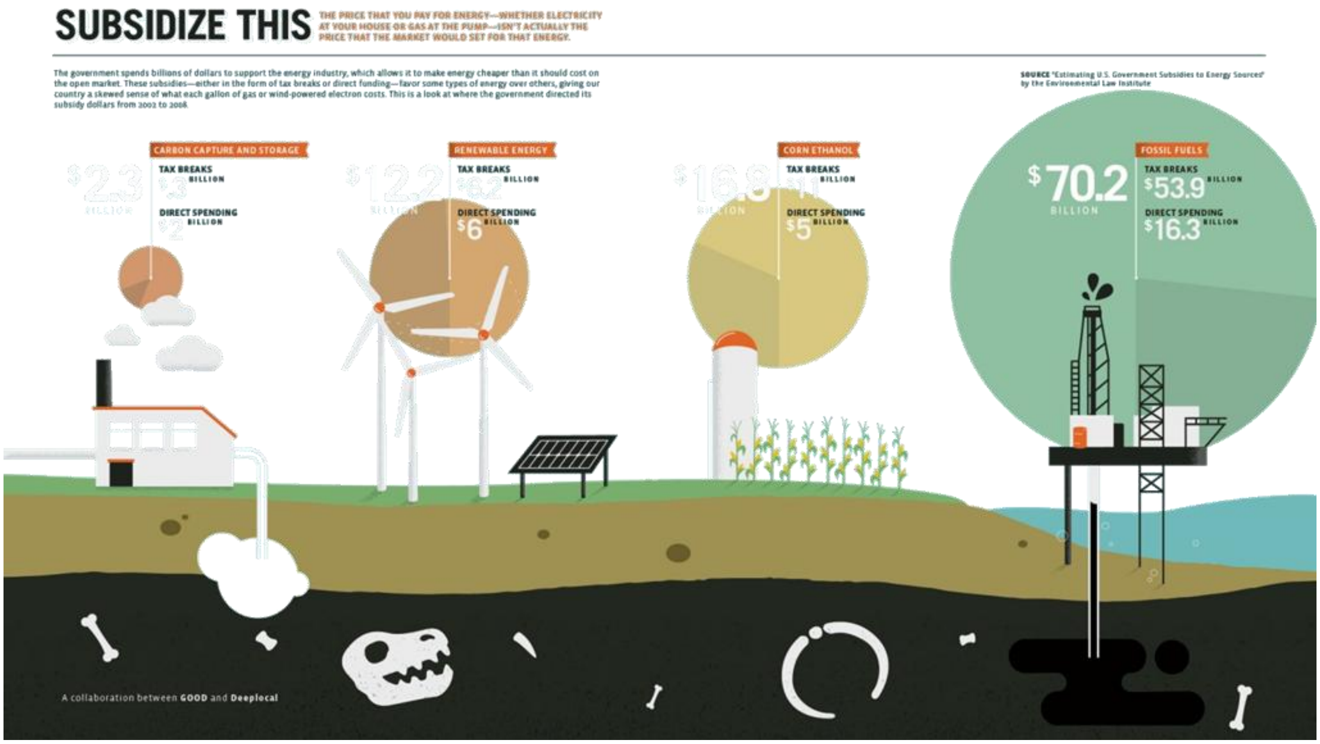


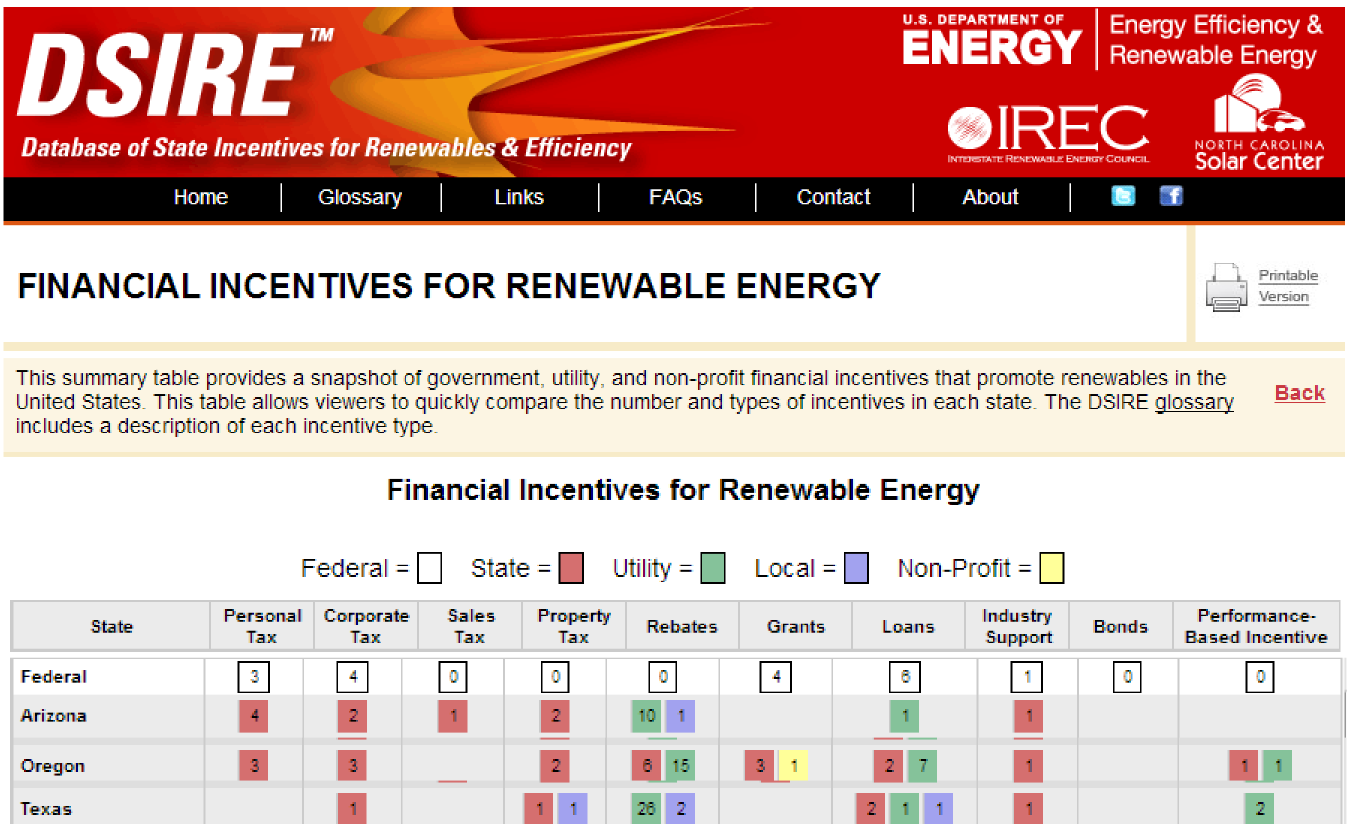
Figure 3.4.14: Estimating U.S. Government Subsidies to Energy Sources: 2002-2008. (Environmental Law Institute 2009)

The above figure and data clarify that the subsidy 'industry' for energy generation in the US is in excess of $100 billion (Environmental Law Institute 2011b), and represents preferential support of both incumbent and future energy alternatives. The magnitude of these investments implies that energy resource sustainability is worthy of efficient and effective management. The U.S. regulatory environment enables an extensive playing field to invest on and support accelerated sustainable adoption. A critical planning step is to optimize subsidy strategies and accelerate sustainable action. Subsidies are a business decision, and most importantly they reflect Community intention by creating policies to enable support of a desired innovation adoption.

Comprehensive sustainable energy strategies for the United States remain elusive, and subsidies are dedicated as need and lobbying efforts influence outcomes. With that as a backdrop, one has to question if current subsidy strategies best accelerate optimal energy sustainability migrations? The

answer is not immediately visible, but subsidies do serve a critical role to enable not only technological and behavioral change, but ongoing promotion of sustainability advancement if properly executed.

Specific to this research, the Database of State Incentives for Renewables and Efficiency (DSIRE) offers a window into state comparisons regarding promotion of residential, grid-tied photovoltaic subsidy from each level of influence be it Federal, State, or Local. DSIRE presents a summary of these subsidy programs by state to assist in comparisons, which is presented as an example in the extract from the website below:



State	Personal Tax	Corporate Tax	Sales Tax	Property Tax	Rebates	Grants	Loans	Industry Support	Bonds	Performance-Based Incentive
Federal	3	4	0	0	0	4	6	1	0	0
Arizona	4	2	1	2	10 1		1	1		
Oregon	3	3		2	6 15	3 1	2 7	1		1 1
Texas		1		1 1	26 2		2 1 1	1		2

Figure 3.4.15: State Comparison of Financial Incentives for Renewable Energy (DSIRE 2013)

Subsidies play a large role in the attractiveness of residential photovoltaic investment. The Federal government maintains and publicizes the current state, which is very dynamic. Note that these

subsidies occur on multiple levels across various entities, and impacts can be dramatic. Across the test cases, subsidies are aggregated and applied on two levels for utility for grid-tied installations consisting of (1) immediate investment offset with purchase and (2) tax benefits. While dynamic and depletable, the following table summarizes test case subsidy status at the time of writing. These data were extracted from DSIRE on September 25, 2013:

Table 3.4.7: State Comparison of Financial Incentives for Renewable Energy (DSIRE 2013, a,b,c)

Incentive	El Paso	Phoenix	Portland
Federal Residential Renewable Energy Tax Credit	30%		
Personal Tax Credit (State)	N/A	N/A	PV: $2.10/W-DC at STC; PV, Fuel Cells and Wind Turbines: $6,000 ($1,500 per year for 4 years), up to 50%
Sales Tax Exemption (%)	N/A (State sales tax is 8.25%)	100% of sales tax on	100%
Utility Rebate	El Paso Electric coordinates an incentive of $0.75 per DC watt for residential projects with a maximum incentive of $7,500 with the available incentives of $212.5k already accounted - funding consumed for 2013 ($425,000)	Residential PV (up to 25 kW): $0.10/watt-DC	Portland General Electric offers an incentive rate through the Energy Trust which enables residential investors to claim a financial incentive of $0.75/watt, up to a maximum of $5,000 with no apparent budget limit.
Property Assessment Tax Incentive	100%	N/A (estimated at 0.5% increased value)	100%

At the time of actual subsidy assessment, (1) El Paso Electric coordinates an incentive of $0.75 per DC watt for residential projects with a maximum incentive of $7,500 (EPE 2013) with the available incentives of $425k already accounted for, (2) Arizona Public Service offers up to $0.10/Installed Watt at time of publication (APS 2013b) with a total subsidy of $2.65 million already consumed, and (3) Portland General Electric offers an incentive rate through the Oregon Energy Trust which enables residential investors to claim a financial incentive of $0.75/watt, up to a maximum of $5,000 (PGE 2013d) with no apparent budget limit. Finally, subsidies for photovoltaic installations are dynamic, and system pricing and return on investment drive support programs to continuously adjust to market conditions as grid parity is approached. This assessment considers a specific point in time, and subsidy regimes should be investigated and reformed on a go forward basis applying the ISDMF.

This concludes the cooperative analysis section of this ISDMF application. Of particular interest is the impact of policy, and more specifically subsidy, that facilitates adoption of perceived sustainable electricity delivery solutions and varies across all test cases.

3.4. Archetype Application to Combat Sustainability Risks

Archetypes are useful to understand the business environment and react to it. As was presented in the Introduction and Literature Review, a wide array of archetypes have been identified and applied in practice. In the test cases, the most appropriate for initial assessment is Accidental Adversaries (Braun 2002, p. 21) as both players stand to immediately gain from residential, grid-tied photovoltaic investment. As was mentioned, three archetypes are reproduced in Appendix B for ISDFM user reference (Accidental Adversaries, Escalation, and Tragedy of the Commons) with many more available.

3.5. Technology Considerations

Technology is considered equally accessible to each test case locality, and not the focus of this ISDMF application. As was described as an assumption, the price per watt and PVWatts generation projections are used for reference, and all assumptions related to those estimates are outlined in the individual Community investment analyses. Those results are applied to calculate comparative impacts as a baseline and directionally accurate data set. Technology performance can vary and is dependent on performance and cost, but this study assumes system performance as defined by the Department of Energy tool PVWatts as an average of available providers and technologies. To restate, technology performance is based on a fixed tilt, poly-crystalline silicon array with recommended derate factors, tilt and azimuth angles (NREL 2013). Market pricing is based on the most recent Federal publication. (EIA 2013b)

3.6. Community Adoption Current State and Trend

Residential photovoltaic grid-tied adoption levels and rates are not easily available in the public domain. Three identified data sources are available in the United States, with content and availablity varying widely in each test case. The first is required subsidy funding use reporting, originating from the Utility as a confirmation step. The second are State driven residential PV reporting systems. Finally, a third U.S. Federal reporting system was identified through NREL and based on voluntarily uploaded data nationally.

Research suggests that these metrics are available to the Utility directly as each grid-tied installation must be verified and registered to manage billing.. In some cases, City installation permits are also issued and provide detail for each residential, grid-tied photovoltaic installation. Estimates based on these registration is applied where possible, and effort was made to close data gaps directly with these companies and agencies. Details are presented throughout this section 3.7. These three confirmed adoption data sources were researched under the above strategy to arrive at the most probable adoption profiles for each test case. Utility participation was either immediately available or constrained, which was proven to enable establishment of current adoption level, rate, history,and confidence levels for each test case ISDMF application.

3.6.1. Utility Program Performance Reports

As a first source, initial research identified that each of the Utilities publish subsidy budget performance metrics. These publications are required to maintain transparency with public financial contributions applied as subsidy through billing. This information is valuable to understand allocation of intended public contributions for renewable energies and more specifically residential PV adoption. For reference, the following program data sources were identified as Utility published adoption records and subsidy payouts for the specified year and reproduced for the time frame referenced. The presented metrics are established reporting tools, continuously updated with subsidy existance, and reflect current adoption rates for the localities and the Utility. While a valid and transparent attempt to document grid-tied residential adoption, the metrics required by the Framework are not readily available through these

data as they are aggregated and only are implicit of actual system installation quantities. Regardless, they are developed to support full data acquisition efforts.In each of the case studies, subsidies are funded by both utility and community engagement, and issue these metrics to provide transparency of allocated budgets to residential subsidy regimes. Results are published for EPE and APS, but could not be immediately determined for PGE from available data.

El Paso Electric

El Paso Electric has been thorough with publication of residential grid-tied photovoltaic installation incentive management and distribution. Their website presents the Solar PV Pilot Program incentive report, which provides information across several years. Upon review, these numbers only provide insight into adoption rate, but does not provide information to more holistically describe the test case installation footprint or level. Current and historical data available is reproduced below:

Home

Information for Customers

Find an Installer
Customer FAQ
About Solar Energy
Other Programs

Information for Service Providers

Current Program Status
Program Guidebook and Forms

Contact Us

Update 1/22/2013: We will begin accepting new incentive applications for the El Paso Electric PV Incentive Program on Friday, February 1, 12 noon Mountain time (1 pm Central time). All incentive applications must be submitted by registered service providers to pvapps@frontierassoc.com. Incentive applications received prior to the program opening date/time will not be reviewed.

Program Status Page

2013 Program Status - updated 2/22/2013

Budget Status	City-Non-Res	EPE	Total
A. Current Budget	$212,500	$212,500	**$425,000**
B. Requested (In Queue)	$0	$0	**$938**
C. Reserved	$120,435	$117,360	**$237,795**
D. Paid			**$0**
# of completed projects			**0**
kW-dc installed			**0.000**
Avg. $/watt incentive			
E. Available to Reserve (A-C-D)	$92,065	$95,140	**$187,205**

Budget Status	City-Non-Res	EPE	Total
Req+Res+Paid as % of Budget	57%	55%	**56%**
Res+Paid as % of Budget	57%	55%	**56%**
Paid as % of Budget	0%	0%	**0%**

Application Process Status	City-Non-Res	EPE
Accepting Applications	Yes	Yes
Approving Applications	Yes	Yes
Incentive Level for New Approvals	$1.00	$0.75

2012 Program Results

Budget Status	City-Res	City-Non-Res	EPE	Total
A. Final Budget	$450,000	$450,000	$250,000	**$1,150,000**
D. Paid	$450,000	$450,000	$236,266	**$1,136,266**
# of completed projects	39	35	13	**87**
kW-dc installed	228.159	350.620	243.631	**822.410**
Avg. $/watt incentive	$1.97	$1.28	$0.97	**$1.38**
Incentive Level for New Approvals	$2.00	$1.75	$2.00/$1.75	

2011 Program Results

Budget Status	City-Res	City-Non-Res	EPE	Total
A. Final Budget	$450,000	$450,000	$450,000	**$1,350,000**
D. Paid	$449,566	$266,770	$443,977	**$1,160,313**
# of completed projects	46	8	37	**91**
kW-dc installed	225.123	160.090	228.531	**613.744**
Avg. $/watt incentive	$2.00	$1.67	$1.94	**$1.89**
Incentive Levels Offered ($/w-dc)	$2.00	$1.75	$2.00/$1.75	

Figure 3.6.1.2: El Paso Electric Texas Incentives Program Status (EPE 2013)

These figures present a reasonable means of understanding Community based collections and dispersion of subsidy for residential photovoltaic projects in El Paso. However, they are presented in aggregate which restricts transparency and detail needed to better understand adoption. This data was

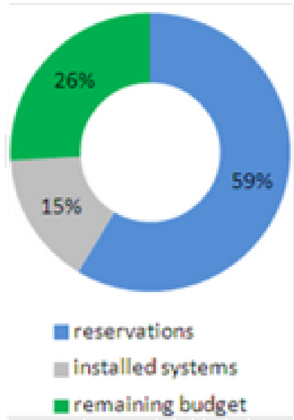
evaluated and escalated directly with El Paso Electric beyond the public domain, and those results will be presented in section 3.6.2.

Arizona Public Service

APS offers subsidy program details on their respective rebate program operation through (Arizona Goes Solar 2013). As they point out, "There's plenty of sunlight in Arizona. And now, with APS rebates and available federal and state tax credits, powering your home with the sun is very affordable. Once installed, solar panels turn sunlight into non-polluting energy. Your home will remain connected to the APS grid, so you'll always have energy anytime you need it. When your system produces more power than you need, the electricity is fed back into the APS grid and you can be credited for that power." (Arizona Goes Solar 2013).

As was indicated in the above table 3.4.7, terms and conditions for these subsidies are constrained to align with market dynamics. Arizona Goes Solar states on their website that, "The maximum incentive is capped at 25kW and 50% of the system cost, while funds are available. The maximum up-front incentive is $50,000 per customer. APS renewable energy rebates are subject to change and funding availability." Further, "Customers must have a signed agreement with an installer prior to submitting an application to APS for incentive funding. To qualify for APS incentives, the equipment must be purchased and installed within 180 days of APS's approval of the reservation application." (Arizona Goes Solar 2013) As of July 2, 2013, program performance was published and is reproduced in the following financial performance figure 3.6.1.1 for reference:

2013 Grid-Tied Photovoltaics (PV) Incentive Rate	
Current Incentive Rate	$0.10



Beginning Budget	Funds Requested (Installed & Reserved)	Remaining Budget
$2,650,000	$2,077,038	**$572,962**

Percentage of Total Budget Requested:						78%
Applications Reserved	Capacity Reserved (MW)	Systems Installed	Capacity Installed(MW)	Funds Installed	Funds Reserved	Funds Requested
2,123	15.53	16.14	4.62	$461,054	$1,615,984	**$2,077,038**

2012 Legacy Reservations				
Applications Reserved	Capacity Reserved (MW)	Funds Reserved	Systems Installed	Capacity Installed(MW)
174	1.37	$194,040	6,712	50.44

Updated 6/28/2013
The residential PVGT carve out is $2.65 million. The total 2013 DE budget of $4.48 million is funded through cancellations.

Figure 3.6.1.1: Arizona Public Service Residential Weekly Program Report (Arizona Goes Solar 2013)

Several important observations can be made regarding the execution and strategy of the Arizona subsidy effort for APS and Phoenix proper: (1) Photovoltaic subsidy funding is transparent, (2) subsidy values beyond the Federal Investment Tax Credit of 30% are comparatively low at $0.10/installed watt

among the case studies, and (3) solar systems are considered home improvements and included in the property tax assessment at a value of roughly 0.5% of added value. As was mentioned, while these statistics are important and provide summary market adoption trends, they do not fully describe adoption beyond subsidy distribution. Section 3.6.2 will expand on this topic for this case study.

Portland General Electric

PGE data dedicated to residential solar subsidy program specifics is not available, but the current program is defined as an incentive program blended into the annual Oregon subsidy budget. For Portland, an incentive/wattDC of $0.75/wattDC with a maximum incentive $5,000 per home is available. (Energy Trust of Oregon 2013) As a subsidy funding source, Oregon's 1999 electric-utility restructuring legislation (SB 1149) required Pacific Power and Portland General Electric (PGE) to collect a 3% public-purpose charge from their customers to support renewable energy and energy efficiency projects through January 1, 2026.

The Oregon Public Utility Commission (OPUC) authorized the Energy Trust of Oregon, an independent non-profit organization, to administer these programs beginning in 2002. Of the funds collected by the electric utilities, 56.7% must be allocated towards energy efficiency programs and 17.1% to renewable technologies. The remaining funds support low-income housing energy assistance and K-12 school energy-conservation efforts. (DESIRE 2013b) The 2012 Oregon Energy Trust budget is reproduced below for reference:

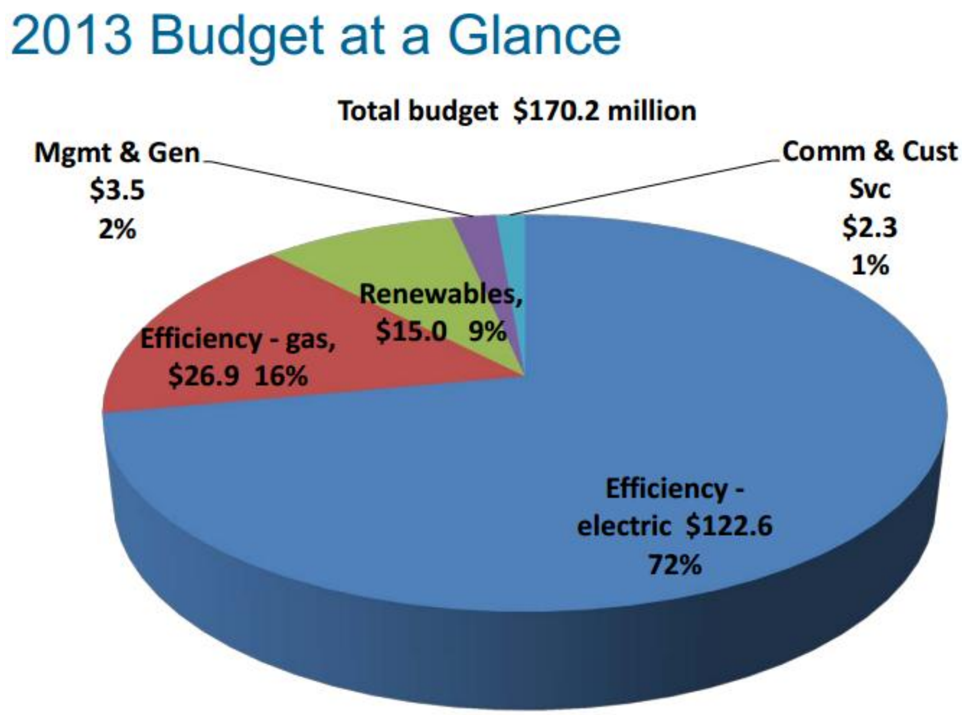


Figure 3.6.1.3: Energy Trust of Oregon Budget Distribution (2012)

Utility Program Performance Report Summary

Utility subsidy performance reports offer an annual, transparent understanding of funding allocation and some sense of current adoption levels and trends. Many significant observations to define subsidy motivations can be derived from these reports, but an exact measurement of adoption level and rate for each case study cannot be determined from these data. With a shortfall of available information for adoption statistics, research turned to other viable resources to include direct contact with test case cities.

3.6.2. Local Community and Cooperative Adoption Assessment Tools

This research demonstrates a significant difference in both Community and Utility participation toward residential PV adoption measurement. As with any public domain investigation, the possibility exists that the information can be found. For this study, an effort to obtain data was made from the

Utility / Community cooperative perspective which revealed sporadic data availability. In all cases, Utility information disclosure and respective web based monitoring tools prove to be the best foundation to establish metric monitoring structure. Local investigation results are discussed for each test case in the following sub-sections.

El Paso

El Paso Electric provides high level program information in the public domain as was documented in section 3.7.1. As this information is not sufficiently detailed to establish accurate levels or rates of adoption, EPE was contacted multiple times over many months for better information. In the EPE case, no adoption information could be made available based on Consumer Rights regulation restriction according to EPE. These efforts are summarized in the following excerpt from an official response from El Paso Electric. An effort to obtain relevant adoption metrics was made over a two year period, and did result in a general market adoption measurement. Obtaining data as an individual Community member toward sustainable electricity management was officially curtailed as reflected through an e-mail from Richard Turner, Assistant Vice President of Corporate Development at El Paso Electric on October 11, 2011.

Unlike other regions in the United States, El Paso (through El Paso Electric) does not provide direct market information due to consumer right regulation. However, later that year as an element of a UTEP grant application to the Department of Energy Sunshot initiative, El Paso Electric was again contacted for participation regarding this same information. At that time Roberto Favela, Superintendent, Distribution Systems at El Paso Electric was assigned to the project by EPE and was able at that time to provide adoption level the grant application effort. On August 26, 2011 Mr. Favela provided the following information regarding El Paso adoption levels:

	"NM service Territory	Texas Service Territory
Total number of customers with a PV solar system	392	83
Total solar PV connected KW	1720 kW	497 kW
Annual Average Coincident Max kW Demand	1.83 kW	2.04 KW"

(Favela, Roberto, personal communication, August 26, 2011).

From these data combined with incentive performance information provided earlier, an estimate of the El Paso residential grid-tied photovoltaic adoption level and rate can be made. Based on the data provided by Mr. Favela on August 26, 2011, the following chart can be developed, and the resultant annual market adoption levels of 60 installations at the end of 2010, 106 in 2011, and 145 by December 2012. The average calculated adoption rate in El Paso is 48 per year:

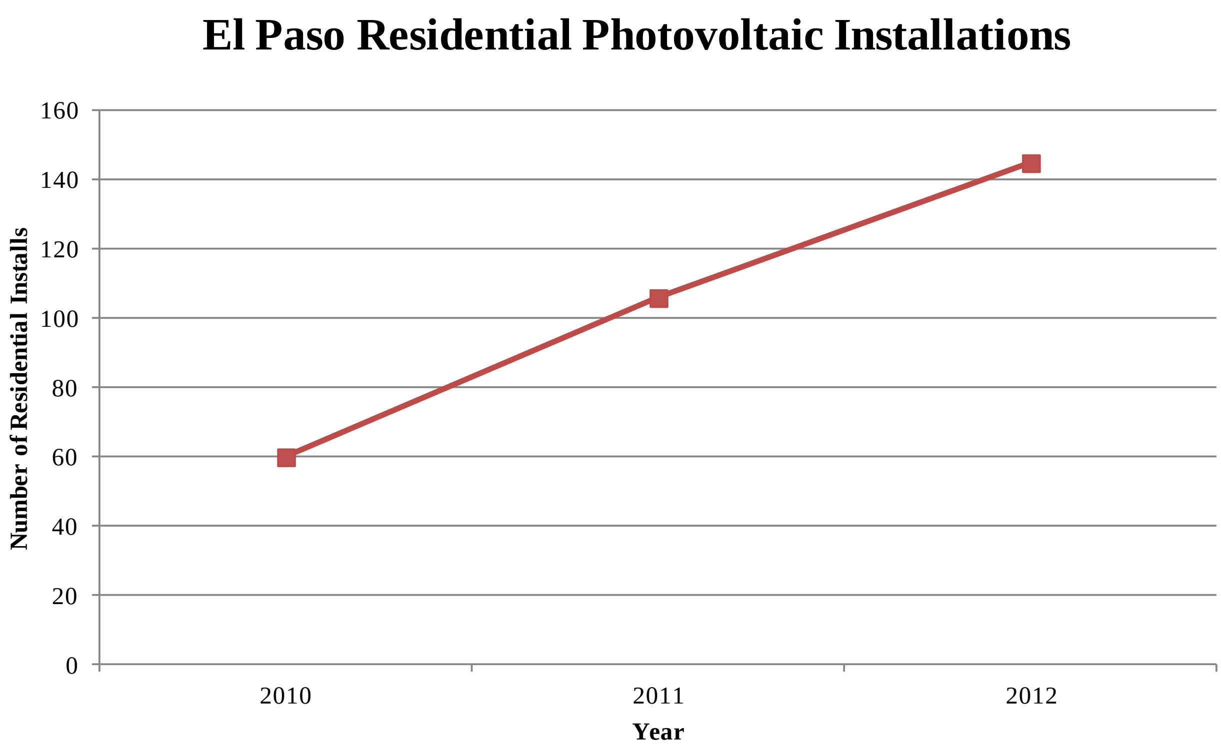


Figure 3.6.2.1: El Paso Grid-Tied Residential Photovoltaic Estimate from assumptions.

The 2013 projection is 193 installed systems by the end of year 2013. The adoption rate seems consistent at 48 installations per year, implying that only Innovators currently adopt (Rogers 2003) and only do so with subsidy funding in El Paso.

Phoenix

Phoenix, Arizona presents a different scenario regarding Utility engagement compared to El Paso. User interface systems to publish updated adoption statistics are relatively recent (2009 is the earliest observed for Portland) and are available to varying levels in the US. Development and use of these adoption measurement tools reflects the recognized need for awareness and transparency in the Community. Per Ostrom's research (1990), open communication is core to promote a sustainable adoption strategy.

Arizona recently engaged a tool to analyze adoption statistics, purchased through State funding. The web based tool publishes residential, grid-tied photovoltaic investment and can be sorted for specific Arizona Utilities. While a start date of the system is not clear, ongoing research indicates that the System came online sometime in 2012. The Arizona State sponsored system is housed within a website called Arizona Goes Solar, and provides relatively current information regarding the photovoltaic installation footprint, size, investor category, and date of installation.

This data can be used to establish residential photovoltaic investment for the Phoenix area and more specifically serviced by Arizona Public Service by area code. For this research, an assessment of Maricopa County was created based on the Arizona Goes Solar data, and the most current output is presented below in two different views to highlight some Arizona Goes Solar System functionalities:

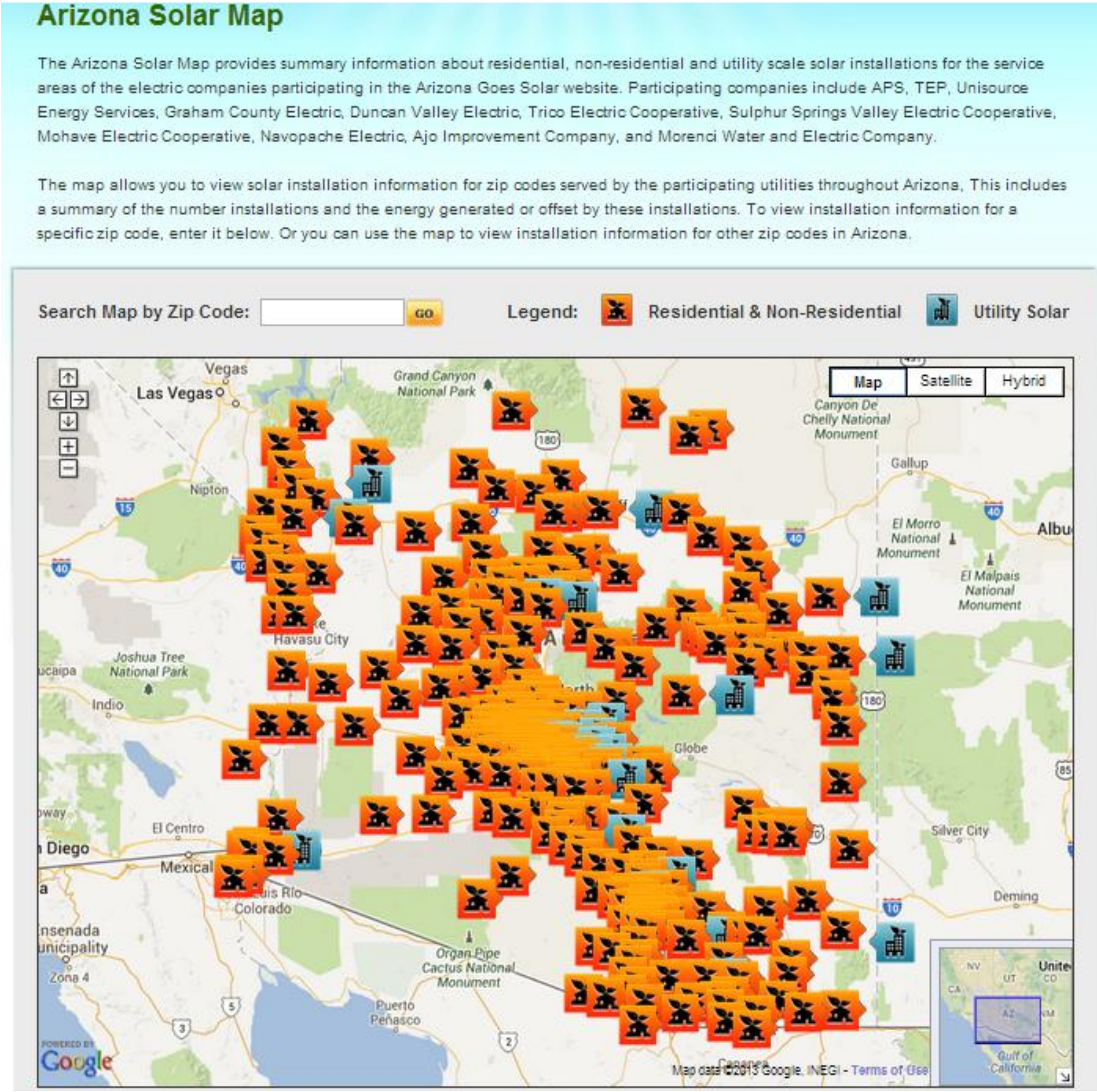


Figure 3.6.2.2: Arizona Solar Map (Arizona Goes Solar 2013a)

Phoenix has seen a n exponential growth of solar adoption from a residential photovoltaic perspective since the launch of these market adoption tools. Utility willingness to provide data offers a critical enabler for market growth. The following figure 3.6.2.3 is a reproduction of the user interface at

Arizona Goes Solar with a data extract sample used to calculate historical registered adoptions by Arizona Public Service:

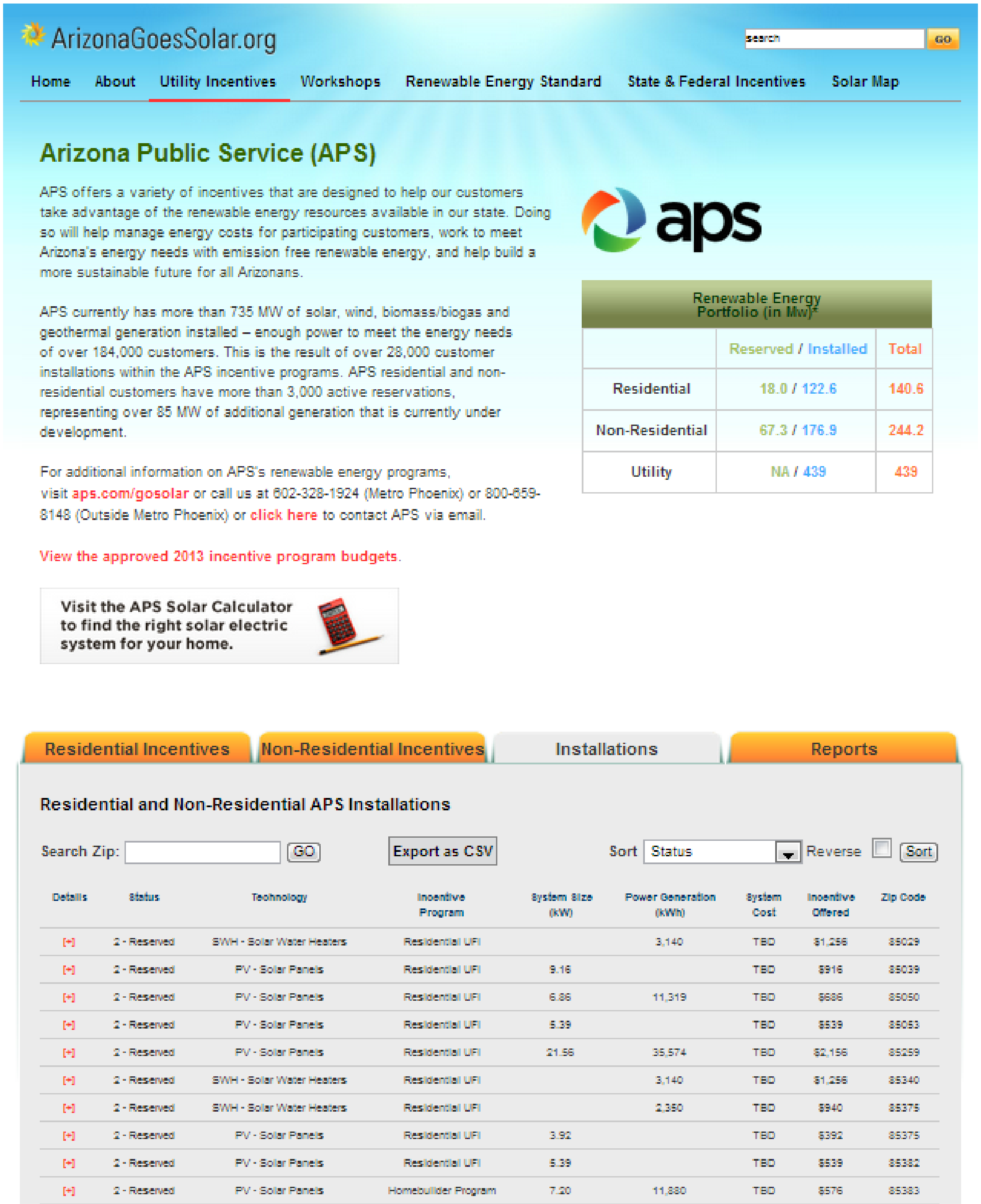


Figure 3.6.2.3: Arizona Public Service Residential Weekly Program Report (Arizona Goes Solar 2013)

The Arizona Goes Solar System offers the ability to download residential grid-tied solar installation information to assess adoption. This output was extracted for Arizona Public Service June 26, 2013, and summarized for Maricopa county zip codes within their service territory to gain both adoption level and rate. The following summary output is based on an extract from Arizona Goes Solar (2013), and was filtered and organized through Access and Excel database tools to arrive at the attached market adoption detail included in Appendix D.

Table 3.6.2.1: Arizona Goes Solar Output Summary - Residential Grid-Tied Photovoltaic Installations

	Year Installed												
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Grand Total
Total Installations	6	9	28	32	127	156	263	1137	2026	2252	4115	6038	16189

Total installations across the period demonstrates an adoption trend toward the "S" curve as described by Rogers (2003). In 2012, a total of 4115 grid-tied residential PV installations were recorded by APS for the defined market, with 1892 installed and 1127 reserved for a total of 3019 for the first half of 2013 (estimated).

From the observed trend and supporting data, an adoption rate of 5,500 installations per year is used as a conservative estimate of APS service territory adoption rate in Maricopa county, with a current estimated adoption total of 13,170 installations plus 3,019 for the outstanding half year for a total of 16,189 estimated by December of 2013.

Portland

More than the other test cases, Portland has a more extensive history of community driven adoption measurement tool use. Their experience highlights continued strategic cooperative intent at the State level, as well as ongoing challenges to maintain effective measurement systems.

In Portland, a consorted effort between the Utility and the Community to enable adoption emerged. In 2009 through 2010 the City of Portland, with the support of the State, was able to secure funds to create a monitoring system capable of publishing specifics of photovoltaic adoption state wide through the Internet. The City of Portland Bureau of Planning and Sustainability contracted the CH2MHill company to construct a web enabled monitoring toolset that provides an overview of photovoltaic installations in the Community (Tooze, David, personal communication, October 10, 2012). Output from this system is available as figure 3.6.2.4 below:

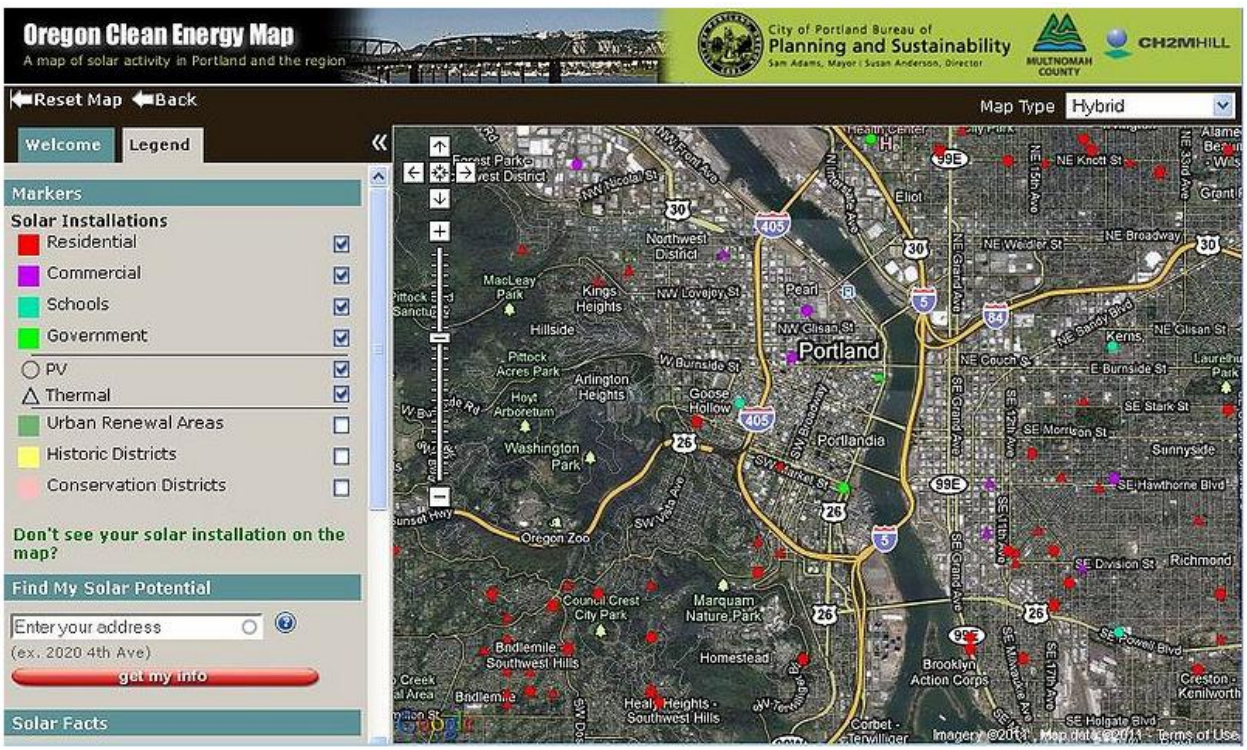


Figure 3.6.2.4: CH2MHill Installation Output for Portland, 2010 (Wikipedia 2013)

This tool was enabled by Federal financial support through Oregon funding efforts. During CH2MHill system use, Portland also witnessed Community engagement through several grassroots efforts, continued education and technology awareness. Community based coalitions to promote smaller,

neighborhood specific mass purchasing were established and termed Community Solar initiatives. This Community based development in Oregon is documented by the National Renewable Energy Laboratory (NREL) on its website (NREL 2013d). Unfortunately, funding for the CH2MHill solar monitoring site was discontinued in 2011. In response, heuristic assessment of Portland must turn to other data sources to assess adoption of residential photovoltaic systems.

Efforts were made to better understand actual adoption levels by contacting personnel directly at the Portland City Energy Sustainability offices. These inquiries were met with uncertainty; Officials were willing to disclose information, but information available to them was 'all inclusive' of renewable efforts. Information available to them does not provide the level of detail required to fully analyze accurate adoption level and rate of strict residential PV adoption.

Initial discussion with officials did however indicate a substantial amount of adoption for the Portland Community. David Tooze, Senior Energy Specialist at the Portland Bureau of Planning and Sustainability, is the point of contact indicated to understand Portland's level of adoption. Mr. Tooze's feedback on October 10, 2012 directed research to Andria Jacob also at the office. Ms. Jacob indicated that " about 2,000 solar energy systems installed in Portland. This includes commercial and residential PV, thermal and solar pool heating systems."(Jacob, Andria, personal communication, October 15, 2012).

Ms. Jacob's feedback is unclear regarding the level of residential photovoltaic adoption as she aggregates all installed residential technologies as contributors from the residential perspective in a single estimate of 2,000 installations. Based on the estimate, ambiguity, and need to establish clear residential photovoltaic adoption levels and rates, other resources were identified to establish the Portland adoption levels and rates. The City of Portland resurrected online publication of renewable installations by partnering with a Geographic Information System (GIS) provider named Esri and the Oregon Department of Energy for data. This system came online and began providing data in early July, 2013. A screen shot of the user interface is included for reference in figure 3.6.2.5 below:

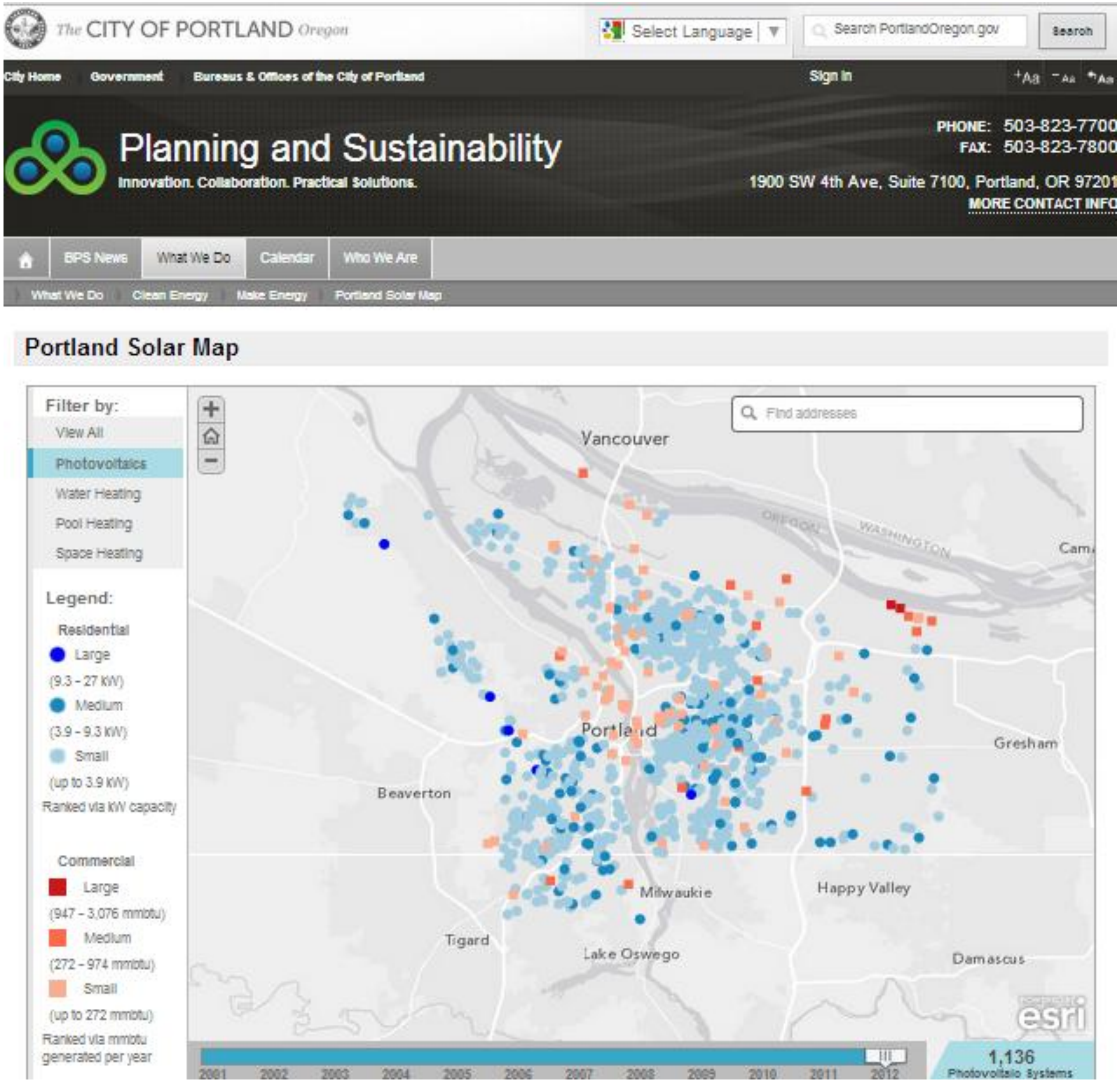


Figure 3.6.2.5: Portland Solar Map Reproduction (City of Portland 2013)

This system is updated semi-annually with data from the Oregon Department of Energy. 2013 figures are not included, however the indicated level of photovoltaic installations is published to be 1,136 at the end of 2012. The system does not allow access to specific datasets as was observed in the Arizona Goes Solar system, so limitations exist to extract installation detail. However, the user interface does allow access to annual installations through the use of the timeline control at the bottom of the

page. The summary below was created by incrementing that control across the recorded time line to arrive at the total number of installations reported at the end of 2012:

Table 3.6.2.2: Portland Residential Photovoltaic Adoption by Year (City of Portland 2013)

	Year												
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013 (Est.)	Grand Total
Total Installations	2	3	12	24	20	39	47	84	395	329	181	182	1318

From these data, installation trend from 2002 to 2010 paralleled the exponential tendencies reflected in a typical "S" shaped adoption curve. (Rogers 2003) Interestingly, the data suggests a flattening of adoption in 2011 followed by a relatively dramatic installation decrease into 2012. For these directional data assessments in ISDMF application, the 2012 installation rate of 181 units per year will be applied for 2013 as a neutral position. As in other test cases, half of the estimated run rate is included with the actual recorded installation level to estimate a total population of 1,136 + 182 or 1,318 estimated total installations by the end of 2013.

These numbers provided via the City of Portland Solar Map help this research arrive at reasonable figures of residential grid-tied photovoltaic adoption for each of the three case studies.

As with any investigation, cross-references further add value to establish validity of metrics. Ideally, a national and accurate toolset should be available to record renewable energy participation. In this case, specifics of grid-tied residential photovoltaic installations should be measured and made available to the public as a sustainability action. The following sub-section describes and quantifies data from the Federal effort as a comparison to local residential grid-tied photovoltaic adoption.

Federal Data Access - The OpenPV Tool

United States Federal agencies recognize the importance of adoption measurement, and a national monitoring software was developed and implemented to address installation statistics. The National Renewable Energy Laboratory (NREL) of the DOE offers a solar monitoring system called The

OpenPV Project (NREL 2013e) for internet based data collection and measurement. As stated on the OpenPV website, "Data for the project are voluntarily contributed from a variety of sources including utilities, installers, and the general public." It further explains that," NREL has 'seeded' the Open PV database by requesting data from most state run incentive programs, large utilities, and other organizations. This initial data collection has provided a solid base of data for the project to launch from and it is our hope that the database will continue to grow through contributions from the PV community and anyone interested in understanding PV market dynamics in the US." (NREL 2013f) Comprehensively, the strategy behind OpenPV is to provide an "up-to-date snapshot" of the dynamic U.S. Solar Power Market continuously based on responsible and accurate data reporting by volunteers.

The NREL strategy through voluntary contribution appears to overcome adoption data availability limitations by allowing anyone access to load and retrieve data. To enable adoption, this OpenPV system validity is based on diligent individual, yet flexible data entry. A basic assumption is that providers load accurate information.

Under this system structure, anyone on the internet can open an account, login, and load informationWhile this flexibility with data entry presents user access, it also poses limitations regarding input data quality. NREL did not overlook this strategy risk, and included a data quality assessment functionality where "Each registered user is assigned a default "score" based on their organizational affiliation. This score is highest for Government users (State, Federal, etc.) because such users are often involved with incentive programs that have a defined data collection process in place. Second are utility and PV installers (and others in the PV industry), and so on. All users who contribute data to the project have the ability to gain a "project reputation" that can impact the score of the data they contribute." (NREL 2013f) Additionally, the OpenPV database is "continually analyzed for corrupt records, bad or invalid data, and outliers such as an abnormal cost to watt ratio. Records found to contain questionable data are flagged and are dealt with on a case by case basis by a member of the Open PV Team." (NREL 2013f)

OpenPV data is considered to complement adoption level assessments presented earlier. A sort was performed using OpenPV results, and these results were filtered based on applicable ZIP codes for

each test case. As this is the only identified assessment tool available for centralized, national data it is important to understand the intent and limitations of the OpenPV effort. The OpenPV graphic user interface (GUI) is reproduced below for reference in figure 3.6.2.6:.

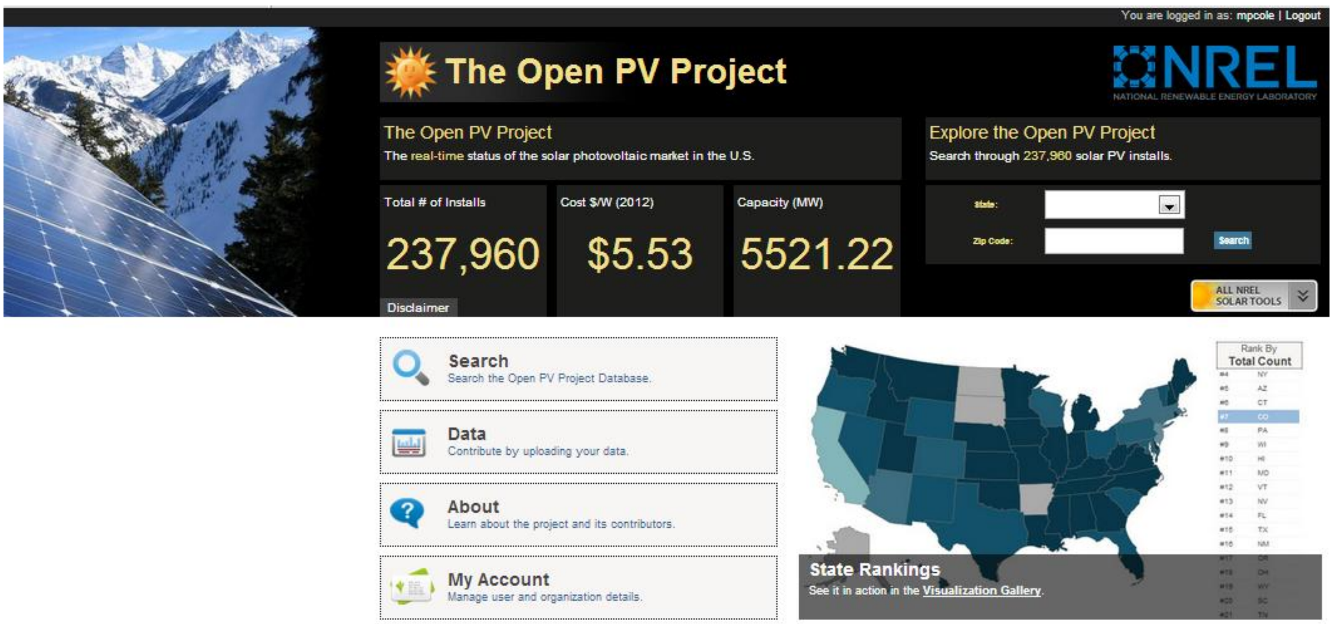


Figure 3.6.2.6: Open PV User Interface (NREL 2013f)

OpenPV proves to be a very comprehensive platform to capture information for national photovoltaic market growth. However, accuracy is of concern due to data sources. With that caveat, the attached excerpt below for Texas demonstrates the breadth of information capable of being recorded in the OpenPV system. In figure 3.6.2.7, the GUI summarizes installation detail by displaying a listing of the base information to define an installed photovoltaic system on the left; on the right is a map of the physical installation location complete with installation detail:

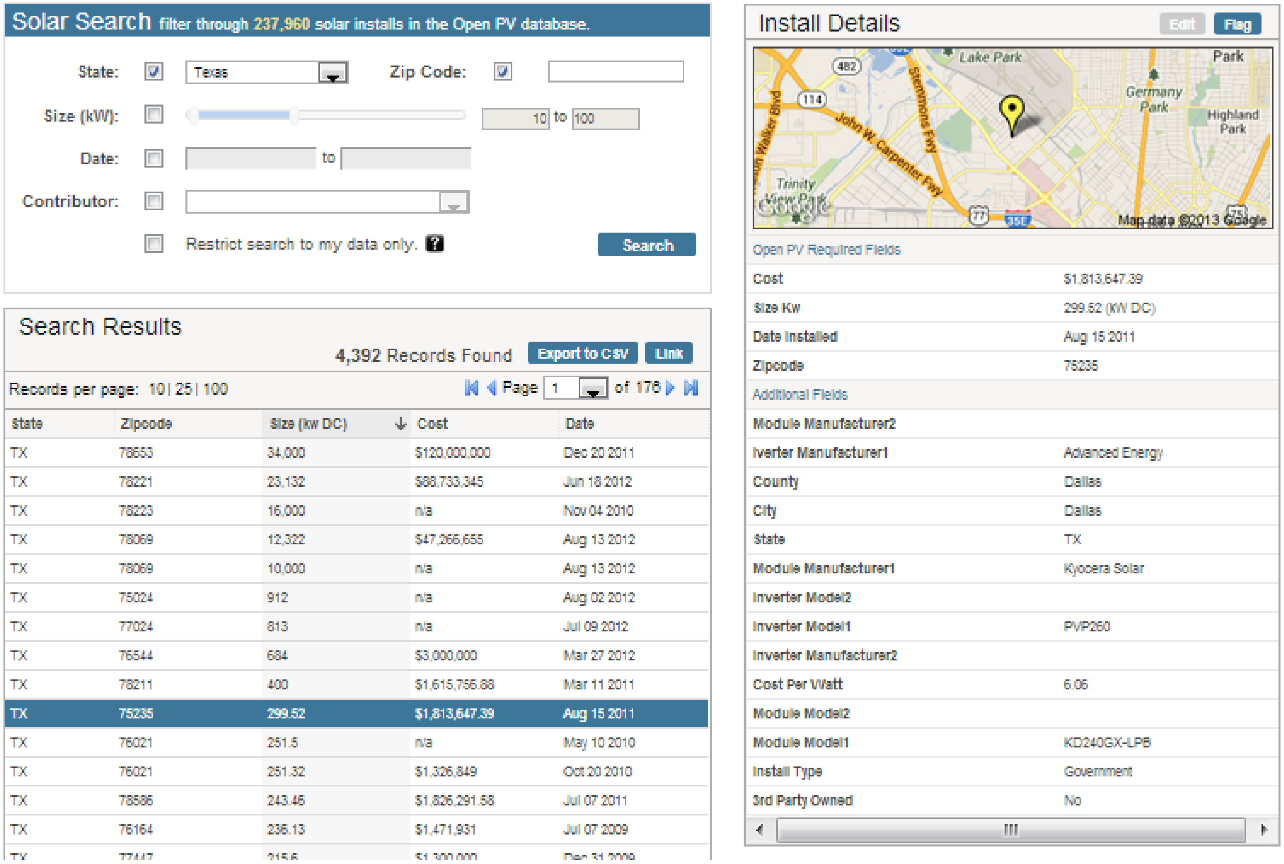


Figure 3.6.2.7: Open PV Output for Texas (NREL 2013h)

In the following table 3.7.2.3, the OpenPV database was queried for state level information to include zip code for the registered installation. Data exports from OpenPV only include seven data elements with four that essentially overlap regarding location, even though many more can be included such as installer, financing type, type of installation, physical address, et cetera which are optional. The seven included, exportable elements are: (1) Zipcode, (2) State, (3) Size (kW DC), (4) Cost, (5) Date Installed, (6) Latitude, and (7) Longitude. An example of the exportable csv database is included below:

Table 3.6.2.3: OpenPV Sample Data Export (NREL 2013g)

Zipcode	State	Size (kW DC)	Cost	Date Installed	Latitude	Longitude
85118	AZ	4.94	14700	6/10/2013	33.354767	-111.444192
85375	AZ	13.08	64092	12/31/2012	33.6587324	-112.3456985
85383	AZ	2.4	16980	12/31/2012	33.7868136	-112.28609
85373	AZ	9.75	53625	12/31/2012	33.6825711	-112.3039728
85383	AZ	7.2	34920	12/31/2012	33.7868136	-112.28609
85132	AZ	1.84	8510	12/31/2012	32.9191925	-111.1891151

With these constraints and capabilities of the OpenPV system defined and understood, queries for the specific test case service territory zip codes of El Paso Electric, Arizona Public Service, and Portland General Electric were operated as OpenPV data extracts. The output from these queries is presented in the following sections for comparison with adoption results presented earlier from other sources.

El Paso

Adoption level and rate in OpenPV is surprisingly similar to the information calculated through use of direct feedback from El Paso Electric blended with the installation history available through the incentives overview. Similar to earlier data sources, the estimated grid-tied residential photovoltaic adoption level approaches 215 at a rate of nearly 48 installations per year.

The following OpenPV results were created based on applicable zip codes and subsequently summarized based on those zip codes by installation and year:

Table 3.6.2.5: Open PV Data Query for El Paso Zip Codes (NREL 2013h)

Count of Date Installed	Year Installed				
El Paso Zip Codes	2009	2010	2011	2012	Grand Total
79821		1	2		3
79901			6	1	7
79902			9	1	10
79903			2		2
79904			2	3	5
79905				6	6
79906			1		1
79907		1		2	3
79911			1	12	13
79912		9	28	12	49
79915		1	2		3
79922			4	2	6
79924			4	2	6
79925		3	4	3	10
79927			2	3	5
79928		1	1	5	7
79930			2	1	3
79932		3	8	4	15
79934	1	1	1	8	11
79935				1	1
79936		1	12	9	22
79938			5	9	14
Grand Total	1	21	96	84	202

Installation rates described in the Federal OpenPV System are slightly higher than the communicated levels obtained directly from El Paso Electric. This is due to the addition of commercial and industrial systems in the OpenPV dataset plus any associated errors.

Confidence level is higher with the more intimate involvement of the data acquisition presented earlier in this Methods section, and so in the El Paso case the OpenPV data is used more to evaluate gaps in the Federal reporting tool based on voluntary use. The previously calculated level of an estimated 215 systems and a relatively linear growth rate of 48 installations per year will be used. These

estimates corroborate between the OpenPV Project toolset and reported estimation data. A summary of all results is provided at the end of this Adoption section.

Phoenix

The identical methodology with OpenPV data as applied to El Paso was used for Phoenix. The same limitations and concerns mentioned in the El Paso OpenPV review apply to the Phoenix data.

An important differentiator of the Phoenix test case is that the data obtained through the Arizona Goes Solar resource provided much more data transparency than is offered for either of the other test cases of El Paso and Portland. Arizona Goes Solar data is provided directly by Arizona Public Service for the zip codes, and was filtered to clearly define the actual number of grid-tied residential photovoltaic systems by zip code from 2002 to present assuming accuracy. This availability provides an assessment basis for confidence assessment of OpenPV data accuracy, and 'opens' discussion of factors that contribute to variance, and value as a system. More detail will be provided on this subject in Results, section 4. Only historical totals will be presented within this text.

Table 3.6.2.6: Phoenix Grid-Tied Residential Photovoltaic Installations per OpenPV (NREL 2013g)

	Year Installed											
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Grand Total
Annual Installations	1	8	23	62	239	248	383	1206	2014	3005	7468	14657

These OpenPV results reflect trends observed in the APS data for Phoenix, and as was previously stated presumably include all recorded photovoltaic installations in the Community. The Arizona Goes Solar data presents a total of 16,189 residential installations and a projected yet conservative rate of 5,500 installations per year. Here, OpenPV suggests an exponential growth pattern with a 2012 installation rate of 7468. If the trend remains exponential, the go forward rate must at least be 7,500 or more. So, Open PV rate and level is assumed to be 7,500 installations per year for a total end of 2013 level of 14,657 + 7,500 or 22,157 installations which aligns with Arizona Goes Solar data.

Portland

OpenPV data was compiled for Portland applying the same method as the previous two test cases. The data below, included as a summary for relative adoption level and rate, is the best adoption information available for Portland and it will be used for ISDMF assessment. Unlike the cases of El Paso and Phoenix, prior attempts for other more reliable data sources did not yield results with confidence higher than this attached summary table 3.7.2.7.

Table 3.6.2.7: Portland Grid-Tied Residential Photovoltaic Installations per OpenPV (NREL 2013e)

	Year Installed												
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Grand Total
Annual Installations	2	1	1	11	24	20	36	51	17	163	201	161	688

The only comparative data currently available for Portland was provided by Andria Jacob, Conservation Program Manager at the Portland Bureau of Planning and Sustainability, who was referenced earlier to state that "commercial and residential PV, thermal and solar pool heating systems" represent an estimated 2,000 total installations in Portland. The OpenPV data indicates 688 total photovoltaic installations with an installation rate (taken as an average of 2010-2012, assuming linear performance as indicated by the data) of 175 installations per year. The total level if applying the estimated installation rate for 2013, the total would be 688 + 175 systems or 863 installations. Ambiguity and general installation estimates in the direct Portland information support OpenPV data as a basis, which is used as the directional estimate for ISDMF application and analysis.

3.7. Summary of Case Study Data

The ISDMF is a guide to identify and integrate resource sustainability factors to effectively and efficiently arrive at sustainable solutions. This Method section presents ISDMF practical application to sustainability decision-making for electricity as a resource, and residential grid-tied photovoltaic innovation adoption as a decision point in three major U.S. cities, Boundaries and Players are defined, and. a comprehensive measurement strategy is developed under the ISDMF process. Available

assumptions and data are presented throughout this Method section to quantify strategic factors by defining current state and projecting sustainability potential of the innovation..The tables below summarize these results separated as individual and cooperative metrics, and based on data available in the public domain as defined in Section 3 of this work. The first table, 3.7.1, establishes the estimated optimal sustainability performance for each test case by category as defined in the Methods section as the applied 'ideal case'. Armed with the 'ideal case' for residential grid-tied photovoltaic adoption, table 3.7.2 quantifies the progress toward optimized electricity management based on the current state and technologies available.

Table 3.87.1: Metric Summary by Test Case Based on the Framework

Electricity Sustainability Metric	Test Case		
	El Paso - EPE	Phoenix - APS	Portland - PGE
Framework Determined for Individual: Community Investor			
Reported Per Capita Annual Electricity Consumption (kWh)	5431.47	5059.72	4908.55
Assumed System Annual Production (kWh)	7788		
Estimated System Size for Annual Production (PVWatts, kW)	4.7	4.82	7.65
Per Watt Initial Purchase Price Break Even	$ 5.80	$ 5.80	$ 3.25
Estimated Current Installation Market Price (Note: Does not include any subsidies) ($/W)	$ 3.50	$ 5.25	$ 6.00
Average System Installation Cost Per Test Case ($)	$ 16,450.00	$ 25,305.00	$ 45,918.00
Net Present Value of Average System Investment ($)	$ 7,605.01	$ 1,804.84	$ (15,100.85)
Calculated Investment Rate of Return (IRR) (or Loss) at Market Price with 30% Federal Tax Credit (ITC) Recovered in Year 1	5.7%	1.0%	-5.2%
Framework Determined for Individual: Utility			
Estimated Peak Generation (MW)	1620	8300	2300
Assumed Marginal Loss Transition Point (20% of peak, MW)	1300	6640	1840
Peak Generation with Potential Marginal Loss (MW)	320	1660	460
Estimated Unprofitable Electricity Units (GWh/Year)	350	1839	504
Representative Number of Average Residential Systems	44941	236133	64715
Federally Published State Retail Unit Rate ($USD/kWh)	$ 0.1106	$ 0.1036	$ 0.0977
Retail Rate Based Sales Value of Unprofitable Units ($USD million/Year)	$ 38.7	$ 190.5	$ 49.2
Average Assumed Marginal Unit Cost Penalty to Utility ($/kWh)	$0.02		
Estimated Average Peak Unit Generation Cost ($USD/kWh)	$ 0.1306	$ 0.1236	$ 0.1177
Estimated Peak Sales Delivery Cost ($USD million/Year)	$ 45.7	$ 227.3	$ 59.3
Estimated Net Loss on Total Peak Electricity Units ($USD million/Year)	$ 7.0	$ 36.8	$ 10.1

Table 3.87.1 (Continued): Metric Summary by Test Case Based on the Framework

Electricity Sustainability Metric	Test Case		
	El Paso - EPE	Phoenix - APS	Portland - PGE
Framework Determined Cooperative Impacts (Full Implementation)			
Assumed Air Quality Installed Unit Impact (CO_2 reflected here, additional detail in text) (kg/kWh)	0.18113458		
Production Average CO_2 Emission for Test Case from EPA (Regional for Utility and All Sources for relative comparison) (kg / kWh) (EPA 2014)	0.57104	0.57104	0.40862
Optimal Framework Application CO_2 Reduction per Year (million kg / Year)	63.397103	333.1064926	91.29182832
Representative Number of Average Vehicle Equivalent - Assumes 5.1 metric tons of CO_2 per car per year on average (EPA 2011)	12431	65315	17900
Water Conservation - Weighted Average Water Consumption Offset with System Installations (gallons / MWh)	396	268	190
Water Conservation - Total Estimated Annual Water Reduction with Full Implementation (US liquid gallons)	138600000	492852000	95760000
Water Conservation - Reduction in Acre Feet (1 gallon = 0.0000030688654573 Acre*Foot)	425	1512	294
Water Conservation - Reduction in Number of Olympic Pools (Assume 660,000 gallons per pool)	210	747	145
Total Optimal Installation Cost @ Current Rate ($)	$ 739,278,376.99	$ 5,975,333,204.93	$ 2,970,416,024.65
Actual Investment 'Out of Pocket' with Federal ITC Subsidy at 30%	$ 517,494,863.89	$ 4,182,733,243.45	$ 2,079,291,217.26
Increase of Capital Preserved in the Community (considered as locality job creation funds)	$ 221,783,513.10	$ 1,792,599,961.48	$ 891,124,807.40
Increase of Community Disposable Income (Net Present Value of System Purchase based on Utility Bill Offset) (is conservative as it only considers economic improvement of residential photovoltaic investors) (Net Future Value compared to Centralized Generation (Status Quo))	$ 341,776,258.35	$ 426,181,402.16	$ (976,867,608.04)
Electricity Efficiency Gain (Demand Side Offset through Education and Awareness, offering bill reduction opportunity to residential investors and enhanced load leveling to utilities)	Future Work Opportunity - Assume no behavioral sustainability impact.		

Table 3.8.7.2: Metric Summary of Sustainability Performance by Test Case

Electricity Sustainability Metric	**Test Case**		
	El Paso - EPE	**Phoenix - APS**	**Portland - PGE**
Current State - Adoption By Source (as of 12/31/2013)			
Population Considered* (U.S. Census Bureau 2012)	827,398	1,488,750	603,106
Current Estimated Grid-Tied Residential Adoption Level - Utility Driven	Provides incentive performance, not totals	Provides incentive performance, not totals	No direct data found
Current Estimated Grid-Tied Residential Adoption Rate (dynamic, installations per year) - Utility Driven	Provides incentive performance, not totals	Provides incentive performance, not totals	No direct data found
Current Estimated Grid-Tied Residential Adoption Level - Community source	193	16,189	1,318
Current Estimated Grid-Tied Residential Adoption Rate (dynamic, installations per year) - Community source	48	6,038	182
Current Estimated Grid-Tied Residential Adoption Level - OpenPV	293	22,157	863
Current Estimated Grid-Tied Residential Adoption Rate (dynamic, installations per year) - OpenPV	91	7,500	175
Rate Tendency	Linear	Exponential	Linear - Decreasing
Registered Start Year, Earliest within the Databases	2010	2002	2001
Estimated Per Capita Installation Level (% of Population)	0.023%	1.087%	0.219%

Adoption Legend - Colors indicate relative confidence level of data:	Best Found, and Applied to Study.	Questionable, but available (Used for Comparative Purposes).	Some data available, but can not be used to quantify adoption metrics.

Current State - Progress Toward Sustainability Solution Based on Adoption	El Paso - EPE	Phoenix - APS	Portland - PGE
Estimated Total Installation Cost Paid by Community	$ 3,174,850	$ 409,662,645	$ 60,519,924
Estimated Net Present Value of Installations Paid by Community	$ 1,467,766	$ 29,218,568	$ (19,902,926)
Retail Rate Based Sales Value of Unprofitable Units ($USD/Year)	$ 1,503,084	$ 126,079,932	$ 10,264,584
Utility Loss Avoidance on Unprofitable Units ($USD/Year)	$ 30,062	$ 2,521,599	$ 205,292
Annual CO2 Generation Avoidance (kg/Year)	272,260	22,837,436	1,859,271
Representative Number of Average Vehicle Equivalent - Assumes 5.1 metric tons of CO_2 per car per year on average (EPA 2011)	53	4,478	365
Water Conservation - Total Estimated Annual Water Reduction Attributed to Current Adoption Level (US liquid gallons)	595221	33789422	1950271
Water Conservation - Reduction in Acre Feet (1 gallon = 0.0000030688654573 Acre*Foot)	2	104	6
Water Conservation - Reduction in Number of Olympic Pools (Assume 660,000 gallons per pool)	1	51	3
Increase of Capital Preserved in the Community at Current Adoption (considered as locality job creation funds)	$ 952,455	$ 122,898,794	$ 18,155,977
Increase of Community Disposable Income (Net Present Value of System Purchase based on Utility Bill Offset) (is conservative as it only considers economic improvement of residential photovoltaic investors) (Net Future Value compared to Centralized Generation (Status Quo))	$ 1,467,766	$ 29,218,568	$ (19,902,926)
Installation Progress Toward Framework Determined Optimal (Current Adoption as a % of Framework Determined Optimum)	0.4295%	6.8559%	Not Applicable (PV Erodes Community Prosperity)

These summarized data suggest an estimated current state residential grid-tied adoption level aligned with a sustainable trajectory in the cases of El Paso and Phoenix, but not in the case of Portland (based on defined assumptions).

Ironically, the most sustainably positioned Community to benefit from adoption proliferation, El Paso, exhibits minimal community interest to adopt. This is in contrast to Portland that demonstrates relatively high levels of adoption albeit at sustainability penalty. Clearly, other factors beyond individual and community financial benefits must affect the diffusion of this grid-tied residential PV innovation. More detailed assessment of ISDMF utility and capability is presented in section 4, Results, by demonstrating how pure economics or beliefs do not govern sustainable actions. These data support that localized and cooperative efforts have more profound effect on holistic sustainability advancement. The Results section 4 summarizes ISDMF theoretical contributions and confirms its value through practical application. The five research questions posed in the Introduction are resolved, and observed case study best practices identified through the ISDMF are presented.

Results

Sections 1-3 of this work describes (1) the need for an approachable, actionable, adoptable framework, (2) the spectrum of framework types available, (3) the Integrated Sustainability Decision-Making Framework and contributing philosophies, and (4) and presents three real world cases to analyze effectiveness and efficiency to enable sustainability solutions. This Results section analyzes the supporting work to answer the five original research questions posed in the Introduction (as sections 4.1-4.5), and provides specific data and observations to support the research answers. Results are suggestive toward future work based on data availability and accuracy, and applied to demonstrate the use of the ISDMF for decision-making strategy development and execution.

4.1. Does a framework exist to facilitate sustainable decision-making and subsequent action?

A sustainability framework is a template for users to apply as a 'check list' to ensure that core sustainability strategy theories are considered in a decision-making process. With the application, the user can increase confidence that key sustainability concepts have been considered. A broad spectrum of frameworks exist, with many tailored to specific communication and action strategies.

This study determined that single framework types are effective for an intended use and audience. Todorov and Marinova (2009) define four base types of frameworks: (1) Pictorial Visualization, (2) Quantitative, (3) Physical, and (4) Conceptual approaches. These types were discussed and examples provided in section 2, Literature Review. But research demonstrates that effective and efficient sustainability framework definition requires the creation of a fifth type, the Combined, which synthesizes the best attributes of base types into a single framework. The ISDMF developed herein falls into this category.

The challenge of a Combined framework is to integrate the four basic types with the most critical sustainability philosophies to create a decision-making process to be used as a standard. This standard should be approachable, actionable, and adoptable to best enable maintained or improved Quality of Life today and into the future.

Many contributors worldwide continuously engage in sustainable strategy development. As sustainability frameworks develop and fall from use every day, one could say that an infinite number exist. The challenge to sustainability innovation is to assess prior work, embrace the best examples, and enhance where needed. Fortunately, all observed examples can be categorized into one of the 5 framework types for comparison. Combined types provide a categorization to refine optimal framework development as they leverage the best components of all into a single representation that can be used as a standard to enable communication between diverse players and arrive at a sustainability improvement trajectory.

4.2. Considering prior sustainability frameworks, what gaps exist and how can those gaps be addressed by an integrated framework based on established behavioral, economic, and technological philosophies?

Comparison between existing and emerging frameworks poses several challenges to identify differentiators to establish one more approachable, actionable, and adoptable over another. An 'infinite' and dynamic number of frameworks are available, so comprehensive assessment is a resource intensive and continuous challenge.

As was demonstrated, decision-making frameworks are developed for a specific use and target population. This characteristic makes them useful within their unique design space and participant set, but can constrain holistic adoption and development of the most effective sustainability strategy. As such, a goal of the ISDMF is to provide users a toolset that can be applied by a comprehensive audience to enable more efficient and effective sustainability action through consistent, streamlined communication by those affected.

Sustainability framework gaps manifest as limitations or omissions of evaluation concepts from minimized, core sustainability philosophies. Decision-making is a participant event throughout the supply chain, and subjectivity in strategy poses the greatest risk to the development of effective frameworks as developers tailor content to their immediate group. (Todorov and Marinova 2009, p. 1218) This Achilles' heel is apparent in the base framework types themselves. For example, Pictorial and

Conceptual frameworks provide the best types to comprehensively address larger audiences with sustainability ideas, but action is better driven by measurement through Quantitative and Physical types. These limitations can be overcome by applying a Combined framework. As described in the Literature Review, Combined approaches open the possibility to address the three core components of approachability, actionability, and adoptability simultaneously.

The Sustainability Framework (SF) developed by the National Academies (NA) presented in section 2.1 comes closest to reaching a synergy of the four base types in combination, and is used as a 'Best in Class' to assess current gaps in frameworks. As presented in the Literature Review, the National Acadamies Sustainability Framework (NASF) was developed for use by the U.S. Environmental Protection Agency (USEPA) to assess risks to natural resources, both direct and indirect. The NASF is designed for use by organizations established to investigate and improve a wide range of resource conditions across supply chain participants. As such, the NASF provides the most developed existing framework for current state comparison to the ISDMF structure.

Gap identification among frameworks is conducted by identifying the best case for general application, and assessing content and presentation for completeness and efficiency. A starting point is the assessment of its governing visioning statement, and analysis of definition and contents. As with the development of the ISDMF, one of the key initial steps to develop the NASF was to establish a definition of sustainability. The NA determined that their framework would apply a widely accepted definition of sustainability, which was proposed in the 1969 National Environmental Policy Act (NEPA) and continuously referred to in U.S. legislation:

> "Sustainability: to create and maintain conditions, under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic, and other requirements of present and future generations (NEPA, 1969; Executive Order 13514, 2009)" (OECD 2013a, p. 12)

This definition is aligned with other comprehensive 'sustainability' descriptors, and is applied as the basis for development of the NASF. The NASF definition closely parallels the WCED sustainability definition from 1987 (section 1.3.3), and is similar yet more wordy than the definition used for this ISDMF development in 2014 ("A state of maintained or improving Quality of Life today and in the future.") Note that each iteration appears to distill Sustainability to more succinct terms while preserving original and core sustainability values.

Assuming a common definition of Sustainability, the NASF process view is presented in section 2.1 of the Literature Review and is reproduced below. Concept grouping is indicated by the numbering scheme and identification circles where applicable for ISDMF comparisons later:

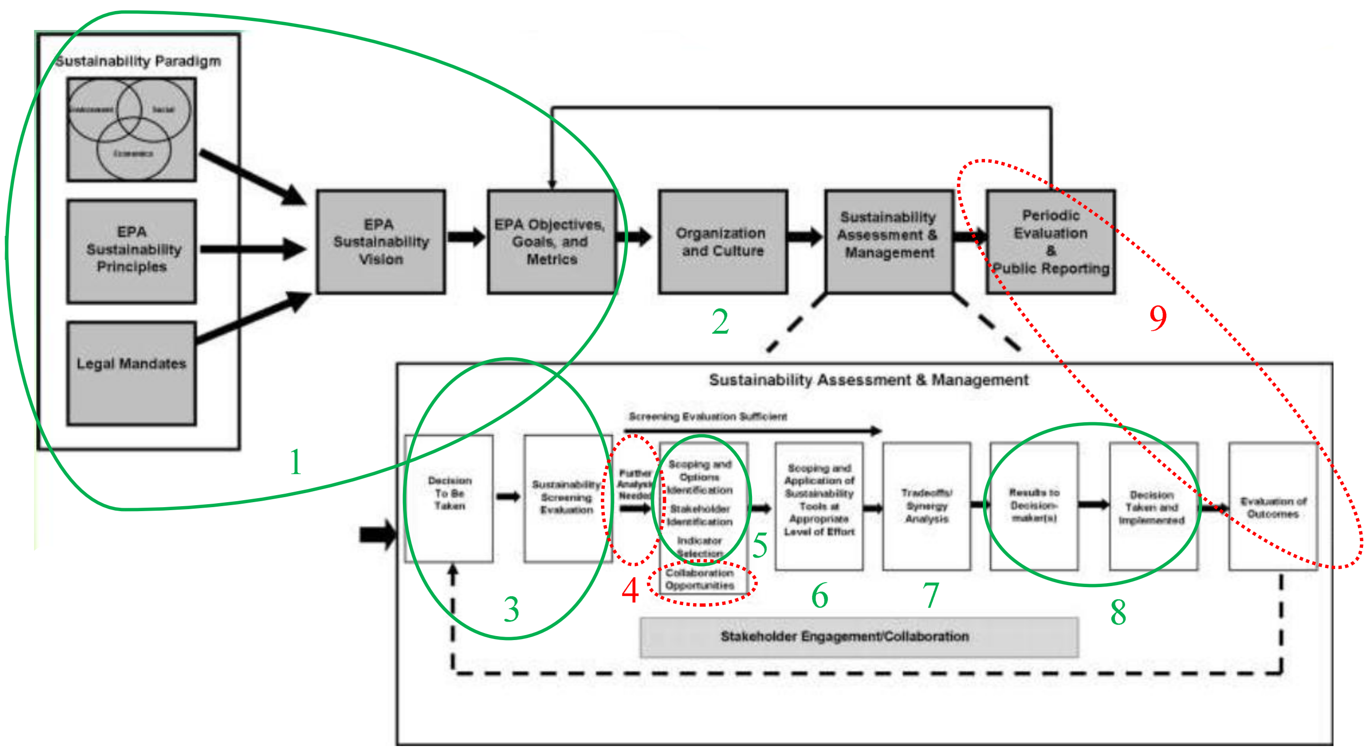


Figure 4.2.1: National Academies Sustainability Framework factor summary (from section 2.1)

The NASF is comprised of 17 unique process steps segmented by topic. These steps can be summarized into 9 separate elements that apply toward sustainable solution development (indicated by

green and red outlines in figure 4.2.1 above). Process indicators 1-3 can be summarized as visioning and background statements, and indicators 5-9 cover scoping and identification, implementation, and continuous measurement.

Proven sustainability theories presented in the Literature Review indicate that the NASF has gaps. The most significant gap is identified directly by the NA in the process definition and is summarized as step 4 across two NASF steps. Immediately following the Sustainability Screening Evaluation step is indicated a descriptor of "Further Analysis Needed", which an is ambiguous user instruction. Based on chronological process alignment with the ISDMF, this undeveloped yet recognized step in the NASF is inferred in the ISDMF to represent a market or 'current state' strategic assessment of options and the likelihood of respective adoption. This is based on player motivation as defined in sections 2.2 and 2.3, and demonstrated through included case studies in section 3, Method.

This first definition gap in the NASF example leads to a second, which is the omission of the adoption / diffusion of innovation contribution factor. The NASF does not mention adoption nor diffusion, which is proven to be a core contributing sustainability theory. (Rogers 2003) This topic extension can be incorporated into element 9 of the comparative assessment.

Omission of Diffusion of Innovation is likely the result of NA tailoring to a focused audience with unique goals. The USEPA performs research to influence policy and monitor compliance, and are not necessarily concerned about adoption by free will. Under their application, it is understandable that a framework tailored to EPA needs would not contain more economic and market based process elements. Otherwise, the content of the NASF includes all other contributory theories included in the ISDMF, in sequence, and subsequently the existing NASF has provided users with a viable sustainability strategy toolset since its public release.

In summary, Combined framework types are best positioned to establish approachable, actionable, and adoptable sustainability solutions. Many Combined frameworks are published, but the best identified example to meet general need was created by the NA for USEPA application. The NASF offers process sequence and factor considerations for effective and efficient decision-making by a user, but presents limitations when considered beyond the USEPA scope. Specifically, the NASF has two

gaps to enable a wider user audience: (1) The 'Further Analysis Needed' and 'Collaboration Opportunities' process steps, and (2) integration of Diffusion of Innovation concepts.

4.3. What alternative framework enables comprehensive resource sustainability assessment?

Prior work and analysis indicates that prior work has gaps, and that an alternative framework can better enable system participants to make more sustainable decisions effectively and efficiently. The NASF most closely approaches an integrated framework that is approachable, actionable, and adoptable. However, two specific gaps were identified in the NASF that could limit sustainability strategy success.

The ISDMF presented in this work closely parallels the NASF in steps and sequence, but advances Sustainability Theory by addressing the two identified gaps of the 'Further Analysis Needed' NASF process step and diffusion of innovation concepts not available. To illustrate these differences, figure 4.3.1 compares structure and content of the NASF and ISDFM, which is followed by table 4.3.1 to quantify the observed similarities and differences between them.

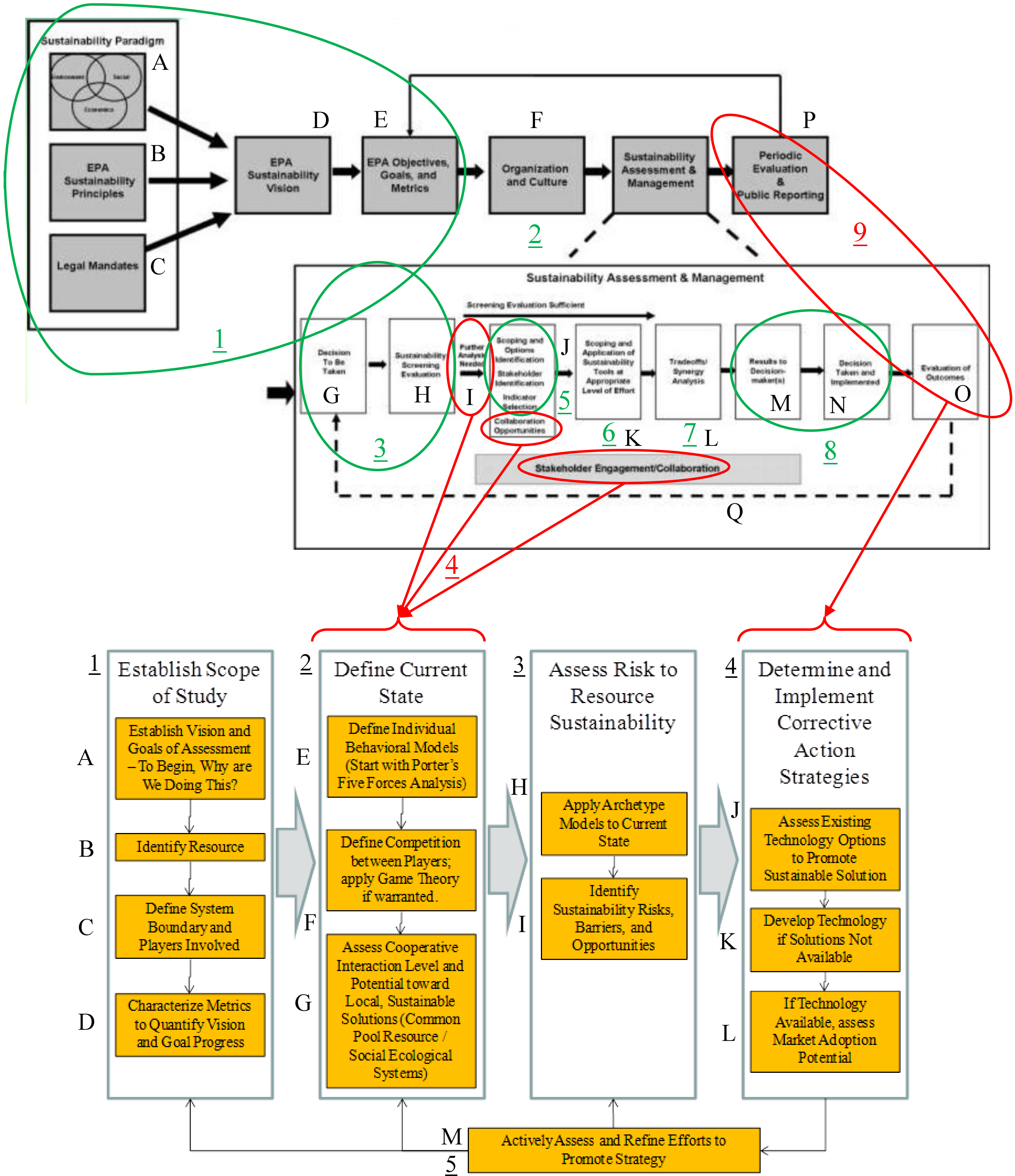


Figure 4.3.1: NASF process view comparison with ISDMF

Table 4.3.1: Content and Structure Comparison of the NASF and ISDMF

NASF Process Number (Underlined Numbers)	General Framework Element	NASF Steps for Topic	NASF Sustainability Element Gap?	ISDMF Process Number	ISDMF Steps for Topic
1	Prior Knowledge and Visioning	A,B,C,D,E	No	1	A,B
2	Establish Resource, Scope and Players	E,F	No	1	B,C
3	Characterize Metrics to Quantify Vision and Goal Progress	E	No	1	D
4	Define Current State	I,Q	Yes	2	E,F,G
5	Scoping, Options, and Player Identification	F,J	No	2,3,4	E - L
6	Options Assessment	K	No	2,3,4	E - L
7	Assess Potential Outcomes (Archetype theory)	L	No	3	H
8	Decision Taken and Implemented	M,N	No	4,5	J,K,L,M
9	Evaluation of Outcomes (Determine and Implement Corrective Action Strategies)	P,O	Yes	4,5	J,K,L,M

	NASF	ISDMF
Unique Process Steps	17	13
Summarized Framework Segments	9	5

From the above analysis, the ISDMF contains all of the components of the NASF and offers with the addition of two critical components to address identified under-development or omission. The ISDMF does so with a reduction of process steps from 17 to 13. Simultaneously, the ISDMF strives to apply more general terminology to step definitions to increase approachability and adoptability beyond the NASF current best practice. With these additions beyond the NASF, the ISDMF is leaner and at the same time more comprehensive. Additional detail on each framework is provided in section 1 (ISDMF) and section 2 (NASF) of this work.

4.4. Is the proposed Framework effective at identifying areas of opportunity and action across a resource management chain?

The ISDMF addresses the identified gaps in the existing best practice of the NASF. By further developing the two additional concepts of economics and diffusion of innovation, the ISDMF is better able to guide users to more effective sustainability action factors and strategies than the NASF. When comparing the ISDMF and NASF based on content, a user can create similar strategies and actions but

will benefit from these two sustainability element additions. In terms of effectiveness comparison, the ISDMF packages the NASF content in a more concise yet complete 'check list' for sustainability decision-making application. Accordingly, the two NASF gaps addressed in the ISDMF afford the user improved strategic perspective which extends application to financially driven markets.

Finally, the ISDMF applies more common terminology. In terms of framework evaluation criteria, the ISDMF improves on the current best practice of the NASF as it (1) is more approachable and adoptable as it is more concise and uses more common terminology, and (2) is more actionable because it integrates additional core sustainability concepts to create improved strategies.

These ISDMF logic improvements over the NASF as a baseline can be communicated through example. Several success factors were defined that can be assessed using the ISDMF by quantifying adoption levels and rates over time within the Community (aka Diffusion of Innovation). The differences in adoption rate between the test cases can be applied to determine relative factor importance toward sustainability strategy success. More effective and efficient behaviors emerge when comparing performance of the three test cases toward sustainable solution advancement .

The three test cases are compared below using historical, normalized percentage adoption based on the sustainability targets estimated in section 3, Method. Note that the Rogers adopter segments are shown for reference (see section 2.4) which would not be considered under the NASF application.

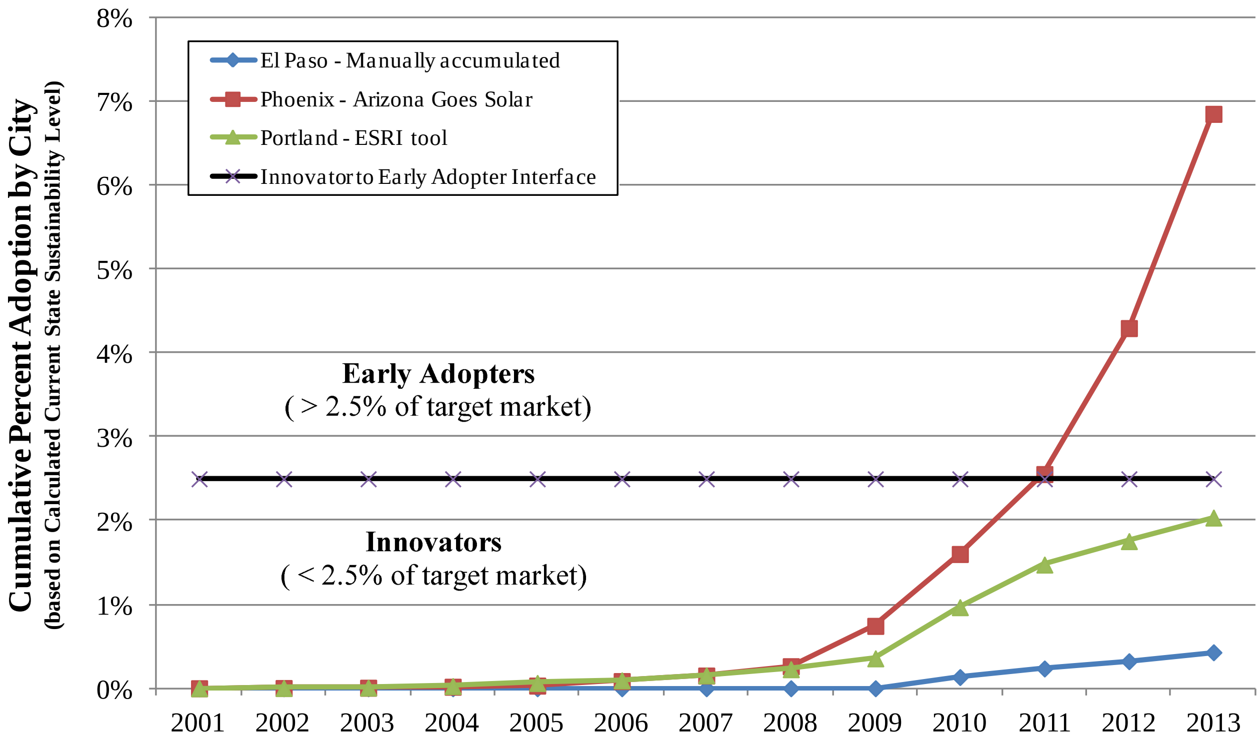


Figure 4.4.1: Normalized Cumulative Adoption Rate per Year by City

Table 4.4.1: Normalized Cumulative Installation Percentage by Year for each test case

	Normalized Installations toward Sustainability Level (Cumulative)					
Year	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
El Paso - Manually accumulated	0.00%	0.00%	0.13%	0.24%	0.32%	0.43%
Phoenix - Arizona Goes Solar	0.26%	0.74%	1.60%	2.56%	4.30%	6.86%
Portland - ESRI tool	0.23%	0.36%	0.97%	1.48%	1.76%	2.04%

Summarized, comparative data illustrates that each test case may operate different sustainability strategies and also be subject to varying factor constraints.

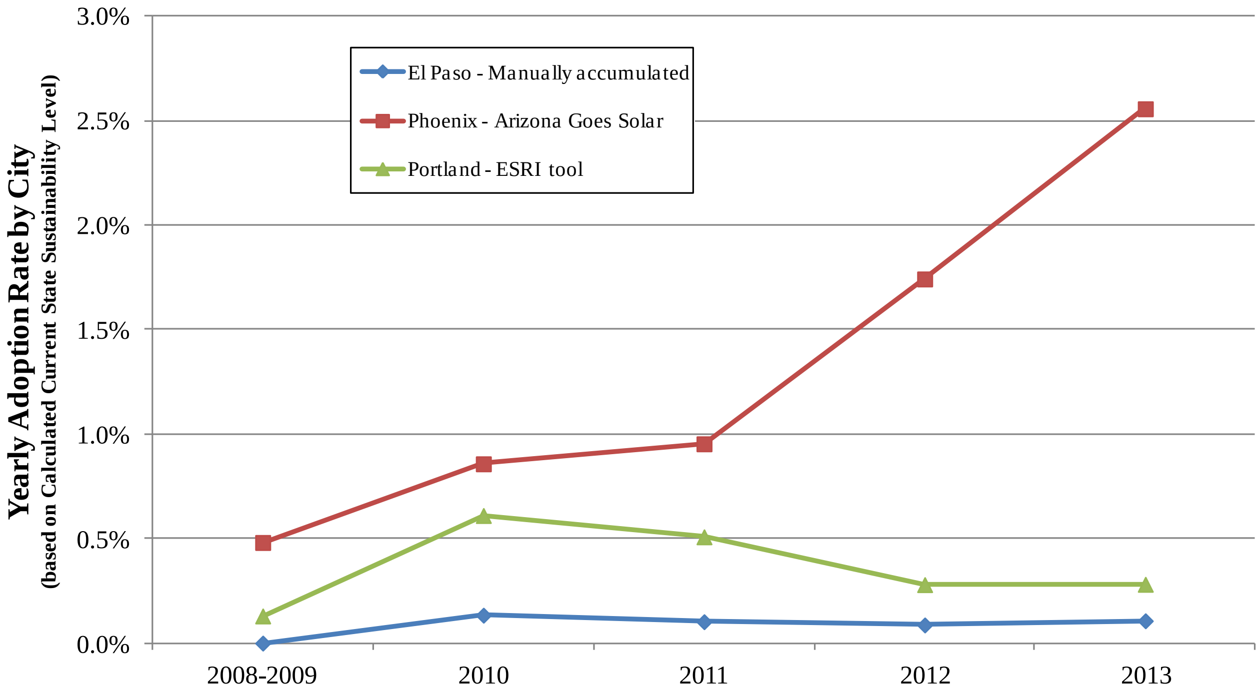
As was presented throughout the Method section 3, several ISDMF driven factors can affect sustainability progress in the residential grid-tied photovoltaic market. Throughout section 3 it was shown that individual motivation, competitive behaviors, and cooperative action can greatly influence a sustainability strategy's success. In the ISDMF, these ideas are summarized as Define Current State

process steps E, F, and G (process indicator 2), as presented in section 4.3. In the NASF, this topic appears to be addressed by the process indicator 4 to very limited utility (steps described as "Further Analysis Needed" and "Collaboration Opportunities") which is unclear. The explicit Define Current State process steps combined with process step L, "If Technology Available, Assess Market Adoption Potential", reminds an ISDMF user to review adoption and contributing factors beyond the NASF approach.

Following the Define Current State process sequence, financial analysis presented in section 3.2 showed that Community members in El Paso and Phoenix receive positive return on investment at current market pricing. In comparison, individual Community investors in Portland actually lose value which is not sustainable. In competition, data demonstrates that the Utilities in each market can increase profitability on decreased revenue through Community investment until more levelized generation profiles are achieved (sections 3.2 and 3.3). However, Utility benefit is a secondary motivational factor as initial purchase is at the discretion of the individual Community member. Assumptions in the analysis support that comparative financial motivation can be summarized return on investment as a factor. These observations would not be identified under the NASF.

The last ISDMF step in the Define Current State element is an assessment of Cooperative impacts to the sustainability strategy. In the residential grid-tied photovoltaic sustainability case, cooperative action resides in the willingness of each player to fully trust and disclose related information transparently and continuously as described in section 2.2.3. (Ostrom 1990) Cooperative and transparent markets stimulate sustainability strategy adoption (Ostrom 1990 and Rogers 2003) and promote investment.

These two factors of individual motivation and cooperative participation are principle summary variables affecting sustainable electricity progress, with others assumed constant among the test cases. To better understand these effects, the data in figure 4.4.1 was further refined to show sustainable adoption performance by year in figure 4.4.2 below:



		Annual Growth toward Sustainability Level (Yearly)				
Year	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
El Paso - Manually accumulated		0.00%	0.13%	0.10%	0.09%	0.11%
Phoenix - Arizona Goes Solar		0.48%	0.86%	0.95%	1.74%	2.56%
Portland - ESRI tool		0.13%	0.61%	0.51%	0.28%	0.28%

Figure 4.4.2: Normalized Yearly Adoption Rate by City

Comparison of the three test cases for this factor indicates a dramatic difference between the adoption rates. As mentioned in the preceding paragraphs, two principle summary variables can create these differences: (1) System return on investment, and (2) cooperative and open communication between the Utility and the Community. If comparisons are made using Shainin Red X techniques (Steiner 2008), it appears that return on investment is not the most significant factor affecting adoption. El Paso has the highest return on investment, but has very low and linear adoption rates; Phoenix has positive, but lower investment return yet has over 20 times the adoption rate of El Paso; In Portland, investment in residential PV at current assumptions actually destroys Community value but has nearly 4 times the rate of adoption of El Paso. This variation surrounding adoption versus investment rate of

return demonstrates that positive investment outcomes contribute to sustainability strategy success, but appear to be less significant than other factors. Again, this observation may not be apparent under the NASF but are recognized when applying the ISDMF.

Cooperative participation is the other variable that can affect adoption in these case studies and is integrated in the ISDMF. Cooperation can take many forms, but generally can be demonstrated in the willingness of each player to share information and work together toward sustainable strategy success. With full participation in the residential PV strategy, both Community and Utility invest resources to enable communication tools and provide detailed, up to date information on installations.

This information availability can then foster sustainability progress. For example, transparency allows investors throughout the supply chain to understand market conditions and better craft investment decisions. Further, individual Community members can use the information to increase confidence in their decision to invest (or not) based on theories of homophily or heterophily (Rogers 2003 and Allen 1993, presented in section 2.4 of the Literature Review).

The history of communication tool use was provided for each test case in section 3.7, which demonstrates efforts either used or in use over time. The 'best in class' system available is the Utility enabled Arizona Goes Solar solution which launched in 2011 in Phoenix. At the other end of the spectrum is El Paso, with no detailed reporting system beyond OpenPV and subsidy allocation accounting. The State of Oregon with Portland General Electric have sporadically applied adoption communication tools since 2009.

In the case of residential grid-tied PV technology, data suggests that publically accessible, internet enabled database tools affect adoption rates. This can be seen when comparing database quality and availability over the period for the three test case cities. These sustainability differences likely would not be identified if only applying the NASF.

A summary of reporting system use and dates is provided below in figure 4.4.3:

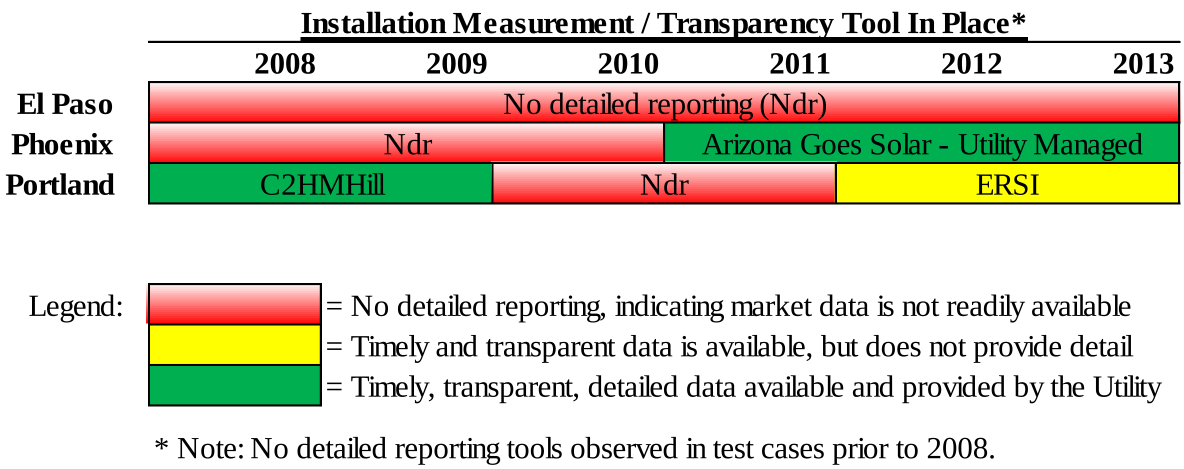


Figure 4.4.3: Timeline of Communication System Type by Test Case City

By comparing figures 4.4.2 and 4.4.3, technology adoption trends are well aligned corresponding to installation data availability to the public.

El Paso is a Community with the highest investment return, but has not engaged transparency tools to demonstrate cooperation. As such, communication was limited to the Federal OpenPV system and subsidy allocation reports. It has the lowest adoption level and rate among the three test cases.

Residential PV investment in Portland destroys Community value under study assumptions, but has much higher adoption rates than El Paso. From section 3.7.2, Portland has engaged reporting tools on two occasions for measurement and communication purposes. Portland exhibited adoption rates growth rates typical of an embraced solution as defined by Rogers (2003). Expected adoption rates continued until 2010, when Federal project funding ended and transparent communication ceased in Oregon through 2011. Adoption rates begin to decline and continue that trend until 2012. During that time without a communication tool, Oregon pursued additional funding and launched a new system provided by ERSI in 2012 which remains in use today. Since the ERSI tool incorporation, Portland adoption rates remain stagnant if not declining aligned with data accessibility.

Phoenix appears to best drive synergistic effects between Community values, economic benefit, and transparency throughout the electricity supply chain. Compared to El Paso, the assumed return on investment is positive which increases community prosperity with residential PV grid-tied adoption, but

investment return is lower due to installation cost and local solar insulation. However, data indicates that some other factor in 2012 seems to have exponentially boosted Phoenix adoption rates.

Prior to 2011, Phoenix was not identified to have any communication tools in place beyond Federal or subsidy reporting vehicles. In 2012, At that time, the State of Arizona launched an internet database for communication referred to as Arizona Goes Solar (AGS). From section 3.7.2, this is a cooperatively developed tool that maintains relatively current installation detail and is fully supported by the local Utility (APS in this case). Since the AGS tool launch, Phoenix has exhibited exponential growth toward the sustainability strategy goal, and at nearly 7% of the adoption goal it remains positioned in the Early Adopter category (Rogers 2003). Of the test cities considered, only Phoenix demonstrates effective Diffusion of Innovation success trend to achieve electricity sustainability for residential grid-tied PV application.

In this study, if assumptions are applied and variables are summarized to the most succinct set, Ostrom, Rogers, and Shainin theory each predict that residential grid-tied PV sustainability progress is most supported by effectively and efficiently communicating adoption wihin targeted Communities. This observation has two resultant tangents: (1) Transparency in a viable Quality of Life improvement market helps support accelerated incorporation of the sustainable strategy (as in the Phoenix case), and (2) in markets where Quality of Life is destroyed by adoption, transparency stifles adoption as initially perceived benefits are not demonstrated and continued adoption may penalize the Community (as witnessed with Portland). Quantified estimates of the relative factor importance between transparency and return on investment can be performed by applying a 2 factor, three level full factorial designed experiment. However, the analysis would require full assessment of another test case characterized by full information transparency and high return on investment which is beyond the scope of this work (see Future Work, section 6).

Beyond this core result of full transparency, detail in disclosed data provides insight to recognize modifications may be required to accommodate external factors and enhance strategy success. As prescribed in the ISDMF and not included in the NASF, personal motivation can be characterized under Porter's Five Forces as a starting point to contemplate individual player investment strategies.

Residential PV installations require startup capital, and individual Community investors may choose to offset those larger initiation costs by engaging a financier. The residential PV industry calls this 'Third Party Financing' which represents external investment in the prescribed technology.

Detail available through AGS suggests that Third Party Financing stimulates adoption, and the concept has been available to all test case markets. Legal platforms have been relatively similar across all three test cases since the most recent related legislation in Texas, Senate Bill 981, effective September 1, 2011, which enables third party financing for residential renewable energy generation. With equal legislative environment, test case Community access to various financing options has been available in all three test case states. However, Phoenix is the only Community that demonstrates ongoing residential grid-tied photovoltaic adoption. A necessary component for this innovation integration is the presence of active installers in the supply chain. Figures 4.4.4 and 4.4.5 summarize installer presence in Phoenix during the study period, which was extracted from the AGS database:

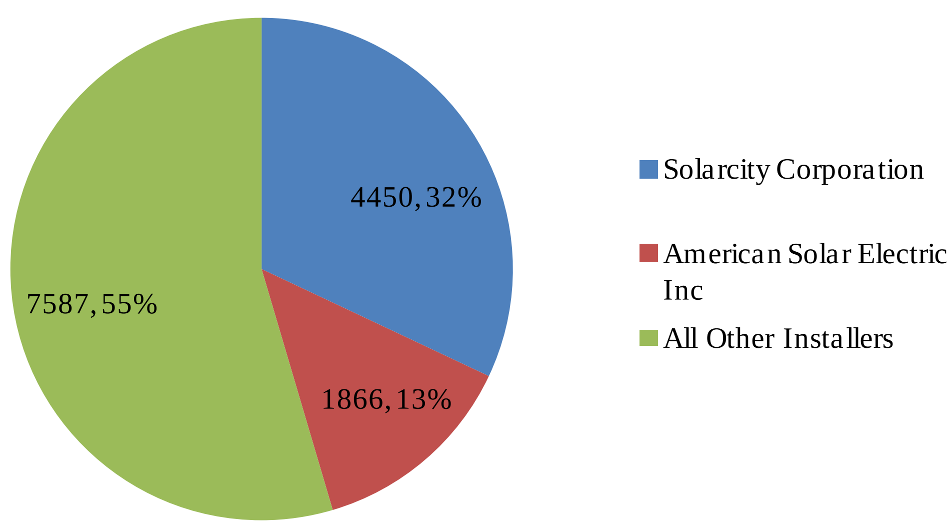


Figure 4.4.4: Cumulative Installations by Provider for Phoenix, Arizona (2007-2013.5)

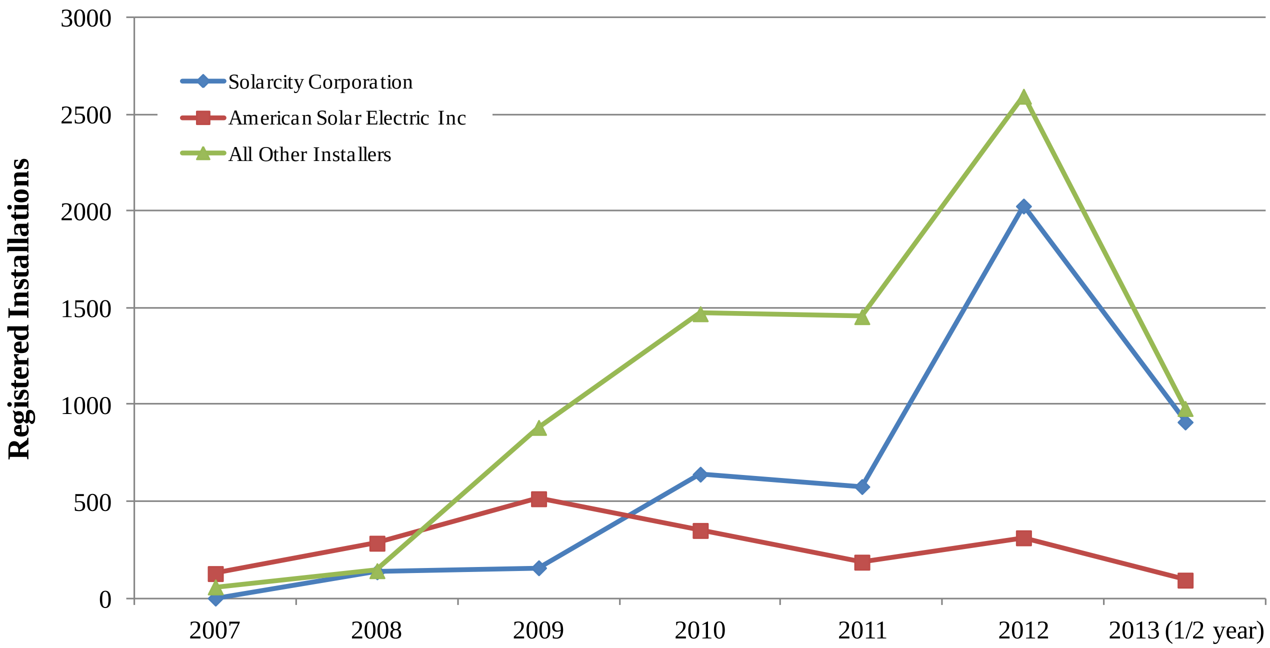


Figure 4.4.5: Installations by Provider for Phoenix, Arizona per Year (2007-2013.5)

Cooperation and transparency enable market options, and SolarCity is an example of a national installer that reacts to local markets that offer cooperative environment. Since 2010, SolarCity has grown market presence to be the top installation company in Phoenix. As an installer and third party finance company, their success indicates that they offer value to consumers and accelerate market adoption. However, external financing and installation options may channel disposable income out of the Community (not directly considered in this ISDMF application). However, critical mass adoption (Rogers 2003) may not be possible without external capital infusion to stimulate markets based on demographics.

The current NASF 'best practice' covers the majority of sustainability framework elements, but presented two specific areas: (1) Cooperation and transparency for Current State definition and strategy development, and (2) market driven sustainability action is based on measured and strategic adoption. The ISDMF addresses these gaps, and examples of use demonstrate the additional theory value beyond the current framework offerings.

An empirical result from these ISDMF driven observations is that Communities striving toward electricity sustainability success must take action and implement a publically accessible adoption

monitoring system. Arizona demonstrates this best practice with its AGS system. Considering this benchmark practice, results suggest that national application would offer sustainability value if a comprehensive, national information reporting system is available. AGS best practices, as an example, could be incorporated into the Federal monitoring system (OpenPV) to leverage synergies and economy of scale of a common electricity sustainability monitoring tool.

Again, these two findings would not have emerged using the NASF as a current benchmark. By closing the two identified gaps and presenting themes more concisely and discretely, the independently developed ISDMF integrates proven framework content while addressing two deficiencies to offer a more complete and approachable development 'check list' for a sustainability strategy designer.

4.5. How can the availability of a new, proven framework contribute to effective and efficient sustainable decision-making?

Frameworks ideally provide users with thought processes to holistically assess options, make decisions, and take sustainable action. An effective and efficient framework must be comprehensively approachable, actionable, and adoptable by all players in a resource management chain to be effective. An infinite number of frameworks are available, and this novel ISDMF best addresses and expands these core attributes among identified frameworks. These improvements are found across several content and communication facets when compared to the current 'best in class' the NASF.

The ISDMF is independently developed based on proven process management, behavioral, and economic theories. As stated in its name, a contribution of the ISDMF is the choreographed Integration of core sustainability theories into a single process as a Combined framework. Demonstrated in section 4.3, this concept is not new as other frameworks like the NASF offer similar structure. However, the ISDMF includes two additional sustainable decision-making factors beyond the NASF theoretical content, and does so with process step reduction and more common wording. The ISDMF then contributes to effective and efficient sustainable decision-making by extending the theoretical content while streamlining process and descriptors.

The first additional factor is Define Current State which consists of three assessment elements: (1) Define Individual Behavioral Models, (2) Define Competition between Players, and (3) Assess Cooperative Interaction Level and Potential toward Local, Sustainable Solutions. The second factor is the inclusion of Diffusion of Innovation principles to monitor and affect player adoption. An example of use and impact is presented in section 4.4. The addition of these theoretical elements improves the actionability of the ISDMF above current identified frameworks.

In conjunction, ISDMF structure offers more optimal streamlining of content and descriptors to promote approachability and adoptability above current frameworks. Word selection and definition of discreet process steps were core ISDMF developmental goals, and the result of those efforts is demonstrated when comparing to the NASF. The ISDMF covers all NASF content, but does so with 4 fewer process steps while incorporating NASF underdeveloped or omitted concepts. Relative to current 'best in class' options, the ISDMF provides a more extensive and necessary range of concepts with fewer, more theory based process steps. When these decision-making steps are executed, this work also offers initial theory descriptions as user starting points to understand core contributory sustainability solution concepts.

These improvements over the NASF 'best practice' suggest that the ISDMF provides a more comprehensive and succinct solution to promote effective and efficient sustainability decision-making. The Framework reminds, informs, and educates users on core sustainability theories and their relative positioning and importance.

A holistic adoption of the ISDMF can stimulate communication between players in the same, base language and by the same process. Educated and involved, framework users will apply the ISDMF (if known and embraced) to continuously converge on the most sustainable Quality of Life trajectory. Sustainable solutions can not be achieved without engagement by all involved players in a cooperative, open communicative environment.

4.6. Results summary and best practice identification

The ISDMF presents a more complete and concise decision-making framework when compared to other identified and analyzed efforts. As demonstrated throughout this work, the ISDMF summarizes critical sustainability factors and order of assessment to assist users when developing resource strategies. The most approachable, actionable, and adoptable framework currently published is offered by the United States National Academies through their Sustainability Framework (referred to as the NASF). A comparison of the ISDMF to the NASF illustrates that published frameworks approach comprehensive 'ideal case' assessment, but that the ISDMF offers two additional elements to promote more efficient sustainability decisions beyond those identified in the NASF.

Specifically, the ISDMF integrates proven sustainability theory to enable users to create more detailed review of economic and behavioral success factors, and secondly it specifically integrates Diffusion of Innovation beyond currently available sustainability decision-making frameworks. As a result, ISDMF application can be practically applied to generate more sustainable decision-making and subsequent action. Value of these ISDMF differentiators is based on comparison to prior work (NASF as a framework best practice) and practical application to residential grid-tied photovoltaic innovation in three large U.S. cities.

The first ISDMF advancement over the NASF is more explicit integration of established economic and behavioral theories supported by the research of Ostrom (1990), Rogers (2003), and others previously cited. These theories, not mentioned in the NASF but indicated in the ISDMF, remind users to assess motivational patterns and player actions when developing a sustainability strategy. In the case of ISDMF application to residential grid-tied photovoltaic adoption, results confirm the importance of open communication as prescribed in prior theoretical works and included in the ISDMF. More specifically, theory and heuristic results through the ISDMF 'checklist' support that one identifiable best practice to enable sustainable action with electricity is the transparent, efficient, and timely dissemination of new technology adoption information among participants. Ostrom and Rogers define that open player communication as paramount to successful strategy execution.

Established theory and test data confirm that cities exhibit more rapid advance to sustainable innovation adoption when accessible and valid innovation statistics are available to the public. In this research, Phoenix fully supports this strategy and benefits from more holistic sustainable action demonstrated by an order of magnitude greater residential grid-tied photovoltaic adoption rate. Portland and El Paso systems sporadically contribute or directly restrict information and, choreographed through the data, realize or forgo sustainability opportunity.. In fact, data supports that even Communities with lower financial or environmental motivation to adopt demonstrate at least an order of magnitude higher residential grid-tied photovoltaic adoption during periods when information is openly communicated to all community participants.

The ISDMF also recognizes the importance of these established contributors and includes a process step to "assess Market Adoption" that non-ISDMF strategists may not otherwise include. This concept integration proves critical to sustainability advancement success as demonstrated in the test cases. With full application, ISDMF users are notified to incorporate adoption studies as a core measurement component, and through these measurements are guided to better foster strategy success beyond currently available frameworks. As a comparative 'best' case, the NASF does not mention adoption as a core sustainability factor necessary for sustainability decision-making. Per Rogers (2003) and others mentioned in the Literature Review, theory and research suggest that widespread integration of a sustainable strategy can be accelerated by measuring adoption. Through this ISDMF integrated effort, researchers and facilitators applying the ISDMF are better able to recognize positioning and can modify strategy when necessary to proliferate effective sustainability solutions in a locality (Ostrom 1990).

An example of the importance of adoption measurement, analysis, and action is observed in the residential grid-tied photovoltaic test case data presented in this research. The Arizona State initiative AGS shares data as prescribed in the first ISDMF differentiator, and provides this information for sustainable action. As prescribed by Rogers (2003), this installation information can be assessed to understand sustainable action adoption. With this current and publicly available adoption information, suppliers are shown to recognize community adoption and invest more confidently.

SolarCity, as a national provider and sustainability enabler, participates as a primary and relatively recent residential photovoltaic system provider in Phoenix. Interestingly, their engagement coincides with the launch of the AGS adoption publication tool in 2011. Data suggest that by gauging adoption statistics available in AGS, SolarCity is better equipped to address market dynamics through both products and services to tailor products and services to the local market. SolarCity reacted to market potential and demands by providing efficient financing, product delivery, and support. Their actions simultaneously promote continued Phoenix residential grid-tied photovoltaic market growth and their business strategy. Specific SolarCity market performance in Phoenix is presented in section 4.4. Portland exhibits similar response to intermittent adoption tool use, where periods of tool availability coincide with increased adoption, and system shutdowns are precursors to adoption downturn. El Paso remains stagnant throughout the period (2009-2014) due to opposition of data publication as documented from responses from El Paso Electric in section 3.

As was defined in detail in the Method section, each case study market has similar population size ranging from slightly over 600 thousand citizens in Portland to nearly 1.5 million in Phoenix, with El Paso representing a middle at the 2012 U.S. Census reported 827 thousand. And, as outlined in the Introduction, two of the test cases are ranked number 3 (Phoenix) and 15 (Portland) in the United States as photovoltaic installation leaders. Test case population and national photovoltaic adoption rankings support test case sets as relevant for ISDMF application to residential grid-tied photovoltaic technology as a sustainability opportunity.

Most important, concept expansion offered by the ISDMF increases user awareness and education to a more complete strategy development toolset over published sustainability frameworks. These sustainability framework advancements are established through accepted theories, framework research, and empirical testing. Results confirm that these sustainability elements must be included in an optimal sustainability framework. Otherwise, resource sustainability strategies are not comprehensively developed or exercised, best practice decisions and actions are not taken, and benefits are not realized.

With these additions, the ISDMF presents a more comprehensive platform for users to develop sustainable strategy as players in a game. If applied and openly communicated across all involved in a

particular resource scope, the ISDMF is a more approachable, actionable, and adoptable framework that can enable consensus of vision and goals, measurement and communication system, and sustainable action can be more efficiently achieved. Application by sufficient individuals as defined 'player' groups can stimulate market change through economic and behavior adaptations.

The mention of 'sufficient' individuals beckons another point: Decision-making is generally stimulated by interest from a select group of 'Innovators' (Rogers 2003) to initiate a change process as included in the ISDMF. Sound and communicable Innovator actions greatly influence holistic adoption (Rogers 2003), as the majority of society observes and subsequently adopts sustainable behavior (Allen 1983). Stated alternatively, sustainability improvement efforts typically originate from small subsets of individuals in each 'player' group characterized as 'Innovators' by Rogers (2003) as an example. And, as was demonstrated through case study, holistic sustainable decisions and actions occur through community awareness, education, and policy management.

In that sense, the ISDMF serves as a toolset and more broadly as a catalyst for individuals within player sets to establish beneficial strategy, actions, and communication to proliferate sustainability decision-making within the community. The vision of the ISDMF is to best equip sustainability actors with a comprehensive tool to proliferate solutions within a community and enable the small population of innovators to engage the remainder to sustainable levels. Dr. Avrind Singhal, Professor of Communication and Director of the Social Justice Initiative at the University of Texas at El Paso, summarized the vision of this work when describing his studies of Positive Deviance, a similar intent to the ISDMF, and its anticipated use: "The focus [of effort] is on discovering the wisdom that already exists, and finding a way to amplify that wisdom within that group." (Singhal 2013)

The ISDMF presents a tool which proven to advance Sustainability Science through theoretical and practical application. The ISDMF is proven to to choreograph sustainability decision-making and more effectively and efficiently than the current 'best case', and accordingly stimulate sustainable action by being more approachable, actionable, and adoptable than currently published frameworks. If embraced by the Innovator sub-set, the ISDMF presents an advancement of sustainability tools to more effectively and efficiently achieve sustainable action across entire communities.

Conclusion

Effective and efficient decision-making is necessary for communities to embrace and implement sustainable action. In this work, the Integrated Sustainability Decision-Making Framework (ISDMF) is defined and proven to equip users with a process to better enable sustainable decision-making beyond current theoretical approaches. The ISDMF integrates established sustainability theory sequence beyond current frameworks through concise inclusion of additional recognized sustainability concepts. For these reasons, the ISDMF provides users with a sustainability decision-making framework that is more approachable, actionable, and adoptable than the identified best practice published by the National Academies (the NASF).

Through theoretical and practical application, the ISDMF design extends sustainability framework science in two key subjects: (1) Inclusion of economic and behavioral theories to support cooperative and transparent engagement among individual and collective resource players, and (2) Diffusion of Innovation theory for localized application by resource chain participants. Addition of these two sustainability factors through the ISDMF enhances user ability to identify and define sustainability value of a resource, establish motivational, communication and cooperation strategies, and determine decision-making best practices that foster sustainable outcomes.

Practical ISDMF application was presented for residential grid-tied photovoltaic innovation in three major U.S. cities. Historical electricity sustainability performance is compared across the test cases, and results demonstrate that ISDMF theoretical additions are valuable strategy development elements. Compiled results confirm that cooperative, transparent data available to players better enables sustainable decision-making and more rapid innovation adoption. In fact, communities that practice transparent, efficient, and timely dissemination of new technology adoption information demonstrate exponential adoption trends when in use, whereas lack of transparency is observed to restrict or virtually eliminate sustainable action even in markets where inherent innovation value is greater. Results suggest that when adoption of an innovation has a net community value decrease, open communication still appears to promote community acceptance of an unsustainable action. Test case data then supports the

conclusion that cities aspiring to promote a sustainable innovation must ensure transparent, effective, and efficient publication of innovation adoption information among players, as is witnessed in Phoenix with APS and is pursued on a limited basis by the national NREL OpenPV system.

The ISDMF also incorporates the concept of unique 'game player' economic and motivational analysis in its structure, which encourages strategists to consider individual motivation as well as sustainability net impacts to the community. Test cases indicate that sustainability strategies in use may not fully contemplate these economic and environmental factors, as was demonstrated by residential grid-tied photovoltaic adoption in Portland. Innovation initial cost was shown to actually exceed investment net present value, which indicates that early adopters in Portland may value other installation benefits beyond financial benefit or not recognize losses adoption may cause. However, sustainable decision-making is focused on improving quality of life over time, and strategies that penalize a player will likely not be fully realized as is observed with Portland. The ISDMF structure helps users recognize these motivational differences and define implications of innovation adoption. A clear sustainability strategy best practice to enable more holistic adoption is to confirm that a proposed innovation can actually provide value to individual players and locality as a sustainable decision and action.

Finally, ISDMF users are reminded to incorporate Diffusion of Innovation theory into strategy development. Test case data supports that if the aforementioned best practices are in place (inherent innovation value and information transparency), adoption measurement and market reaction can accelerate solution effectiveness. An example was developed in section 4 regarding Phoenix and the Arizona Goes Solar (AGS) effort to provide detail and tools used by system providers such as SolarCity. In that example, AGS provides specific installation information to allow not only measurement at the state level, but includes sufficient information for providers to apply diffusion of innovation theory and target specific customers through installation location and demographic profile. As a sustainability promotion example, SolarCity has grown over the past 3 years to dominate the market, and at the same time has stimulated the installer community to become more competitive and accelerate adoption convergence to critical mass (Rogers 2003) in Phoenix. This growth likely would not be possible without the State of Arizona commitment to not only provide transparent data, but to also include

diffusion of innovation based toolsets in AGS. This is another example of a best practice identified in a test case, and demonstrates an action that a city should take to foster sustainable innovation adoption.

The prior three examples of identified best practices illustrate the importance of framework content expansion found in the ISDMF beyond current offerings. As these topics are not mentioned in other frameworks, key innovation factors could be overlooked and optimal sustainability decisions and actions may not be integrated in a strategy. Theory inclusion in the ISDMF inclusion improves the likelihood of successful action while maintaining similar approachability and adoptability as published best practice frameworks. Accordingly, the ISDMF presents a next iteration of sustainability framework definition and improves user ability to analyze and develop sustainability strategy and action.

In summary, this work presents the following sustainability science contributions:

- The ISDMF presents a more comprehensive and concise decision-making framework than identified during the research period. This contribution can enable decision-makers at all resource chain levels to more effectively and efficiently assess sustainability of an innovation.
- Each contributory theory of the ISDMF is choreographed and summarized in sections 1 and 2 for user reference and background while operating the framework.
- Residential Grid-Tied Photovoltaic (RGTP) technology is used as a case study innovation and evaluated across three major U.S. cities of El Paso, Phoenix, and Portland. Data at the time of analyses indicate that El Paso and Phoenix have an opportunity to embrace this innovation toward energy sustainability, and that Portland would be unsustainable under the ISDMF application conditions.
- Test cases demonstrated a key strategic guideline when determining general estimates of sustainable RGTP adoption. While specific data for a given defined community is optimal for calculation, it can be challenging to obtain in the public domain. An initial estimate of 20 percent peak generation can be used when determining viable market potential in communities where adoption is sustainable.

Future Work

Initial ISDMF development covers a broad theoretical and practical range of assessments toward effective and efficient sustainability decision-making. It distills existing framework efforts toward societal prosperity, and integrates core sustainability concepts to arrive at a more complete sustainability logic sequence. An entire science is accessible on this topic, and this research indentifies and compares published sustainability framework types, analyzes best practices and gaps, and converges on a novel sustainability strategy development process.

The ISDMF is designed to apply to any innovation or community combination, and will gain further approachability, actionability, and adoptability through continued use. Accordingly, Future Work for this effort is to propagate ISDMF application and establish its value in the marketplace. Based on this initial work, indoctrinated users can apply the ISDMF and create sustainable outcomes. If more widespread applications are documented, a library of data can be developed and consolidated across innovations and communities to return 'lessons learned' and 'best practices' using the common ISDMF platform. These results can then be configured for innovation and community comparisons, and current state system best practices and projections can be made.

As an example from Chapter 4, quantified estimates of relative transparency and return on investment factor importance for residential grid-tied photovoltaics were discussed. The original scope of this work was unable to quantify best practice impacts as at least one additional test case is required. Investigation indicates that more quantifiable outcomes can be estimated by applying a 2 factor, three level full factorial designed experiment with the addition of another test case characterized by full information transparency and high return on investment. This addition, which is beyond the scope of this work, will allow quantitative factor assessment and a planned future work.

This work also reveals projects to promote residential grid-tied photovoltaic adoption and sustainability through case study and respective comparisons. The first, and perhaps most impactful project to accelerate sustainable adoption and enable all U.S. communities is to converge on a transparent, cooperative communication platform for this industry. Today, these systems are observed to be State driven and supported by multiple public and private functions as reviewed in section 3. These

systems are proven critical to influence innovation adoption. This effect occurs even in environments where financial sustainability erodes with each individual adoption. If operated in a locale with sustainable resource availability, these systems have been shown to accelerate sustainable innovation adoption.

As Future Work, a project remains to develop the most efficient and effective means of adoption communication and a potential solution is found with the national, NREL operated OpenPV system. Today, it provides a common communication platform for all U.S. cities to enable transparent communication. However, OpenPV currently contains data integrity compromises as entry is voluntary and flexible. While this strategy helps enable approachability and adoptability of the tool, but data inaccuracy compromises actionability of the toolset. In the grid-tied environment, Utilities are fully enabled to provide certified adoption data. If data management and communication best practices are integrated into OpenPV, its established infrastructure and current design could help ensure transparency and diffusion of innovation measurement capabilities and consolidate best practices into an existing toolset.

A second project to enable residential grid-tied photovoltaic sustainability is to openly publish sustainability performance of the innovation to the community. Under ISDMF analysis, an innovation must have inherent sustainability value to warrant further action. The ISDMF definition prescribes that two levels of sustainability be considered. First, strategists must consider the immediate impacts to the individual (Porter, 1979), and then assess net community impact (Ostrom, 1990). When these two analyses create a net benefit, an innovation can be considered sustainable. A Future Work is then to maintain and publish these sustainability benefits or losses by community, similar to the analyses presented in section 3. Note that metrics should be provided for capital cost ranges, as innovation pricing and performance can vary for a given innovation and application. A common sustainability value communication template will enable a community to ensure that residential grid-tied photovoltaic investment does create sustainability, which can protect the community from unsustainable or destructive action. As a potential project applicable to the test cases presented, these innovation value metrics can be included in the OpenPV development effort described in the preceding paragraphs.

The ISDMF represents sustainability lessons learned from a broad array of resources. If embraced, its users can march forward and be better prepared to create sustainable decision-making and action. Three specific examples of Future Work projects are reviewed above, and each of them can contribute to more widespread ISDMF usage. Internet based tools also offer great diffusion opportunities to propagate ISDMF awareness and education, as do enterprise, consulting, and academic paths. Each will be pursued to promote widespread ISDMF use. However, care must be exercised to preserve the ISDMF as intellectual property (IP) to enable its growth. But, through Future Work, the ISDMF can be a readily available and continuously improving tool to promote prosperity and sustainable decision-making.

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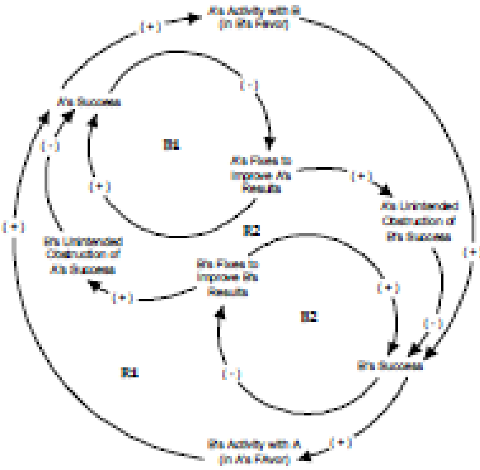
Appendix A

Model Category	Application	Benefits	Limitations	Observed Use
Pictorial	Present visual relationships to describe high level sustainability concepts.	Highly approachable and effective tools to communicate importance of decision steps and factors	While they illustrate 'grand schemes' and develop general philosopy, clear solutions are not provided.	General Communication of Sustainability Theory.
Triple Bottom Line	A specific pictorial representation of the interaction of environment, economics, and social justice. Nearly all models use this approach as a basis for development.	Widely publicized and accepted pictorial representation of core relationships within the Sustainability Community. Offers essential criteria for high level assessment of a sustainable nexus.	Unless incorporated with other models or knowledge, this pictorial model stimulates sustainability thinking but does not clearly illustrate action.	Very broad - This model is applied to serve as a starting point for nearly all models assessed for this study.
Quantitative	Generally a resource specific, numerically driven assessment individual, localized requirements and subsequent contribution to sustainability of given resource.	Incorporates measurements and numerical study to establish sustainability plans. Often incorporate substantial planning and team efforts based on high initial model costs.	Often these models are nested within the approaches of select groups, and may not be approachable by the larger community which limits effects.	Applied by select organizations to document theories based on physical observation.
Quantitative and Goal Setting	An extension of Quantitative methods, where identified sustainability factors have reduction or transition to alternative resource delivery methods are prescribed to meet defined goals	Provides participants with objective sustainability goals. Often these efforts result in conservation and innovation adoption to achieve enhanced sustainability when percieved as demanded by a controlling entity.	Goal setting implies that defined objectives are well founded. The limitation is that if governing bodies do not fully realize sustainable concepts, the resultant goal setting is not well founded and may not best promote sustainable action.	An extension of quantitative application to set metrics for a group to strive toward impact within their respective scope of influence.
Physical	Based on measurement of physical resources to quantify 'real world' potential causes and reduce uncertainty in theoretical models to understand trends of sustainability assessment.	These approaches are fundamental to all approaches as they provide physical observation and analyses to justify investment in future outcomes.	Physical models are limited to the scope of measurement capability, and when considering resource limitations are governed by considerations of the investigation entity. Accordingly, these models are limited by 'stovepiping' of consideration related to the investigators, and are challenged to engage the larger public involvement.	These models are applied to consider limited local investigation that provides focused assessment of sustainability. As was mentioned, often they set sustainability performance as a measured output, but do not clearly identify root causes and solutions.
Conceptual	These models are linked to humanity's waking up to the limits of its natural environment and the negative impacts that population and its development have been having on it.	These models are very effective at presenting concerning attributes of larger scale implications of individual behaviors. They offer inference to larger scale impacts of each participant's behavior, and how wide scale extrapolation of these behaviors can affect the larger whole.	Conceptual consideration is subject to assumptions as determined by their developers. They face scrutany, and unless combined with physical and quatitative models to clearly establish effects, are subject to scrutany.	Conceptual models are typically applied to project negative sustainability outcomes in an effort to engage a given community through fear. They generally consider key sustainability factors and project catastrophic outcomes if community members do not embrace prescribed behavioral actions to create desired outcomes.

Appendix B - Accidental Adversaries Archetype

Accidental Adversaries

Accidental Adversaries is similar to the Escalation archetype in terms of the pattern of behavior that develops over time. It is different from it insofar as the intent of the parties is concerned. Accidental Adversaries begin their relationship with win-win goals and objectives in mind, generally taking advantage of their respective strengths, minimizing their respective weaknesses, with the objective of accomplishing together what cannot be achieved separately.



Generic Archetype

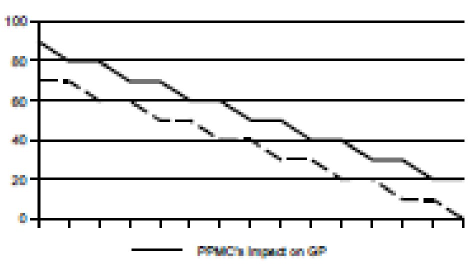
Unwittingly and unintentionally, one party ("the party of the first part") takes an action that the other party ("the party of the second part") interprets as outside the spirit, if not the letter, of their understanding. The "offended" party perceives that the action gives the "offending" party unfair advantage in the partnership (at best) or harms the "offended" party (at worst). The spirit of partnership turns to one of contentious adversaries,` typically as a function of the mental model(s) each party holds. Rather than communicate and engage in dialogue, the offended party assumes (a) it knows everything there is to know about the action (including the foreknowledge that it was willful and hostile), (b) there is no point in discussing it, and (c) their only option is to right the wrong through retaliatory action.

In reality, the first party may not be aware of its action's "harmful" of "hurtful" nature. When the second party retaliates, the first party is as surprised and wounded as the second party, and proceeds to make the same assumptions that the second party did. The first party's recourse? Retaliate.

Once the adversarial (partnership turned sour) relationship takes hold, the behavior is very similar to the Escalation archetype. However, the outer reinforcing loop is still available to the parties should they suspend their mental models and engage in dialogue. The root of misunderstandings, unrealistic expectations, performance problems or mistakes can be revealed, giving the parties a fresh start on their partnership.

Dynamic Theory[8]

This archetype states that when teams or parties in a working relationship misinterpret the actions of each other because of misunderstandings, unrealistic expectations or performance problems, suspicion and mistrust erode the relationship. If mental models fueling the deteriorating relationship are not challenged, all parties may lose the benefits of their synergy.



Behavior Over Time

Behavior Over Time

The trend of each of the adversaries follows a similar direction and rate of change, with one of the adversaries trailing the other (the delay as information travels through the systems and is interpreted). The pattern will

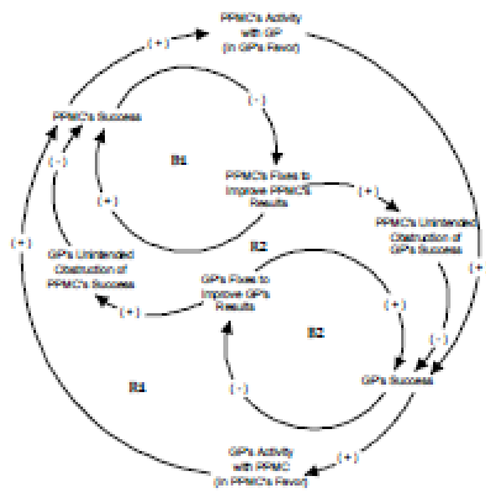
show periodic leveling periods, though overall the trend will be in a direction that adversely impacts both parties.

Application[9] *- Collaboration*

Many cooperative efforts begin on a good note only to deteriorate over time, often as the need for collaboration deepens. This archetype helps the parties to a collaborative effort gain insight into how the actions of one party are filtered through mental models to produce unintended interpretations.

Example

In the early 1990's the Physician Practice Management Corporation industry emerged. PPMCs purchased the hard assets of a practice in return for a percent of revenue for operational services rendered. Initially the relationships fared well. Eventually however, when performance and growth lagged, physicians became uneasy with the relationships and began to interpret every move by the PPMC as potentially (or actually) injurious to theirs interests. The result was the downward spiral of both parties' interests.



PPMC and Group Practice

Prescriptive Action[10]

- Revisit the original opportunity that brought the parties together into a collaborative relationship.
- Use the archetype to identify the origins of adversarial attitudes.
- Renew the Shared Vision of the collaborative effort and commit to Team Learning.

Seven Action Steps[11]

- Reconstruct the conditions that were the catalyst for collaboration.
- Review the original understandings and expected mutual benefits.
- Identify conflicting incentives that may be driving adversarial behavior.
- Map the unintended side effects of each party's actions.
- Develop overarching goals that align the efforts of the parties.
- Establish metrics to monitor collaborative behavior.
- Establish routine communication.

What Does This Really Mean?

The lesson of Accidental Adversaries lies in the power of mental models to supply all too ready explanations of situations. Unless judgement is suspended these mental models can drive one, both or all parties to conclusions that bear remote resemblance to the underlying reason the "breach" in the relationship occurred in the first place, if indeed any breach actually took place.

There is also a lesson on Shared Vision in this archetype. The degree to which the parties hold a vision in common and have articulated their deep needs and expectations is a significant contributor to tempering reactions of the parties when breaches are perceived.

Appendix B - Accidental Adversaries Archetype (continued)

Breaches in the agreement(s) may happen; the probability of deteriorating into Accidental Adversaries is decidedly lower when the parties believe there are overarching values and objectives that unite them in Shared Vision.

Shared Vision will contribute insight to the extent that partners actually engage in helping fix problems (or problem symptoms) in their partner's organization because of their understanding of the long-term impact their efforts will have on their own firm's success. This suggests that Shared Vision is connected to a sense of mission higher than money, that a sense of purpose to customers and an underlying, shared sense of organizational values and culture must be the bedrock of the partnership in the first place.

The archetype also draws attention to Team Learning. If the partners in the venture adopt a principle of continuous joint improvement and learning, the probability that breaches to the partnership will happen in the first place is diminished, as well as a higher probability that if and when misunderstandings, unrealistic expectations or performance problems do occur, the parties will have mechanisms in place to meet each other half way and work them out.

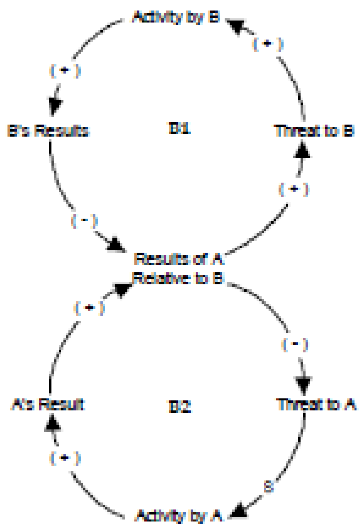
Appendix B - Escalation Archetype

Escalation

A commonly held belief of competition is mounting an appropriate response to the actions of competitors (a) to sustain one's own competitive advantage, (b) to maintain momentum toward gaining competitive advantage, or (c) because that's what managers are supposed to do.

The Escalation archetype presents an irony of management - in the name of protecting and/or furthering the best interests of their organization, managers engage in escalating behavior to the point where they harm their organizations and reduce the value to customers, stakeholders and shareholders.

The archetype also presents an opportunity to think expansionistically, the behavior described by the archetype itself being the [at least partial] result of reductionistic thinking. By expanding their view, managers may find the means through which an encompassing, unifying or overarching goal may be established whereby they discover and option to the perceived need to resort to escalation as a primary competitive response.



Generic Archetype

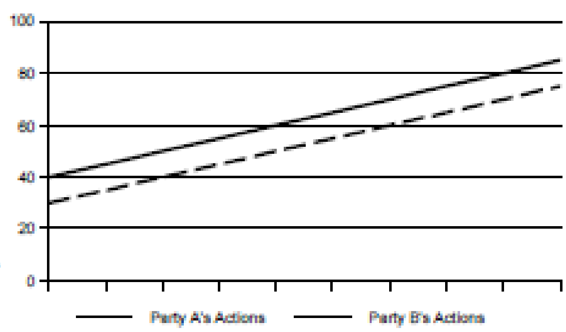
Dynamic Theory

The Escalation archetype occurs when one party's actions are perceived by another party to be a threat, and the second party responds in a similar manner, further increasing the threat. It hypothesizes that the two balancing loops will create a reinforcing figure-8 effect, resulting in threatening actions by both parties that grow exponentially over time.

Behavior Over Time

The behavior of escalation is relatively simple and predictable. The actions (and reactions) of each party are similar in nature, though they become increasingly competitive as time goes by.

What the Behavior Over Time graph does not illustrate is the potential for collapse if the escalation goes on for too long.



Behavior Over Time

Application - Competition

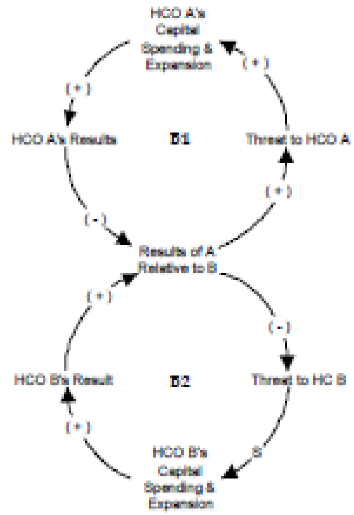
One of the reasons we get caught in escalation dynamics may stem from our view of competition. This archetype suggests that cutthroat competition serves no one well in the long run. The archetype provides a way to identify escalation structures at work and shows how to break out of them or avoid them altogether.

[Appendix B](#) - Escalation Archetype (continued)

Example

In the health care industry, especially in a geographically defined market, it is not uncommon for competitors to engage in a campaign of erecting buildings as a tactic for securing market share. Each facility is seen as a threat by the competitor, who after some delay, will respond in kind. This can continue for some time until the cost of doing so becomes prohibitive and the escalation stops.

This may result in one competitor's eventual market dominance (if it had the resources to support the construction boom) or in one competitors collapse due to overextending itself financially.



Example: HCO Expansion

Prescriptive Action

- Identify the relative measure that is pitting one party against another, and explore ways it can be changed or other ways the parties can differentiate themselves in the market place.
- Quantify significant delays in the system that may be distorting the nature of the threat
- Identify a larger goal that encompasses the individual goal of both parties.

Seven Action Steps

- Identify the competitive variable. Is a single variable the basis of differentiation between competitors?
- Name the key actors in the dynamic.
- Map what is being threatened. Are your actions addressing the real threat or preserving a status quo value which may no longer be relevant?
- Reevaluate competitive measure. Can the variable that is the foundation of the game be shifted?
- Quantify significant delays that may be distorting the nature of the threat.
- Identify a larger goal encompassing both parties' goals.
- Avoid future Escalation traps by creating a system of collaborative competition.

What Does This Really Mean?

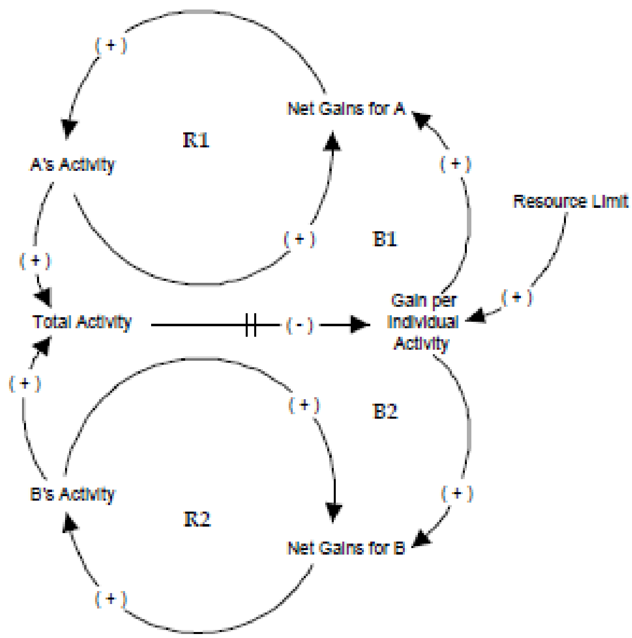
This archetype is difficult to apply - it appears to strike at the heart of the core tenets of free enterprise. Thinking and/or behaving any other way could have ramifications for the manager and the firm - engaging in anti-trust practices for example.

It may be that this archetype may find its value in the public policy arena, or in industry and/or community based assessments of the needs, expectations and requirements of customers and other stakeholder constituencies.

Tragedy of the Commons

The Tragedy of the Commons provides unique insights into the effect that an un-systemic approach to organizational structure can have on overall, long-term performance.

The commons in an organization is a resource (people, materials, space, tools, etc.) that is simultaneously made available to multiple people and/or teams. The initial rational for creating the commons is typically economies of scale.



Generic Archetype

As each person or team claims their "share" of the commons, within the context of the goals and objectives that they have set for themselves, they regard the commons as being uniquely available for their own purposes. Although their lack of awareness of the demands other people or teams place on the commons are not the result of thoughtless disregard, the effect on the commons is the same.

As each person or team increases their demands and expectations of the commons in the name of their own goals, the commons itself finds itself under steadily increasing pressure to perform while simultaneously feeling that its control over it own destiny steadily erodes toward collapse. In the case of commons such as materials or space, there is no conscious awareness of increased demand, but the concrete, physical limitations have no elasticity, and the satisfaction of people or teams placing demands on the commons erodes.

As aggregate performance of the commons slides, several consequences can be felt in the organization. One, individual or team performance declines as the erosion of the commons affects their ability to meet individual goals and objectives.

Two, aggregate organizational performance erodes as the interaction and interdependency of multiple individual and/or team performance begins to reflect the declining performance of the individuals or teams.

Three, organizational goals themselves begin to erode and to reflect the diminished ability of the commons to support the goals and objectives of the individuals and teams that depend on the commons. This can have far reaching consequences in terms of the firm's competitive advantage in the markets in which it competes.

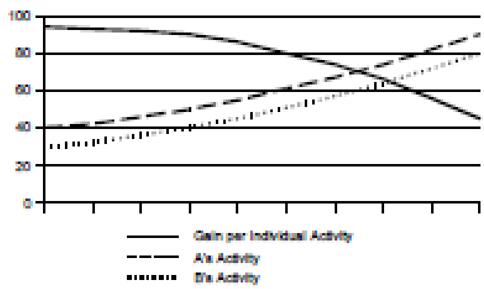
Four, the commons itself deteriorates as a valued and valuable resource to the point where it is regarded as a cause of failure rather than success. When these perceptions become embedded in people's collective assumptions, they can lead to deep beliefs about the organization and its ability (and willingness) to be successful in the long-term.

Dynamic Theory

This archetype identifies the causal connections between individual actions and the collective results (in a closed system). It hypothesizes that if the total usage of a common resource becomes too great for the system to support, the commons will become overloaded or depleted and everyone will experience diminished benefits.

Behavior Over Time

Any time a declining trend is seen in the overall performance of each part of the system even as it increases its demand on common resources, there is a good possibility that a Tragedy of the Commons is taking place. This is often accompanied by puzzlement, as each party placing demands on the system cannot understand why their demands are not being met, which typically results in the party increasing its demands yet further. This may continue until the commons collapses.



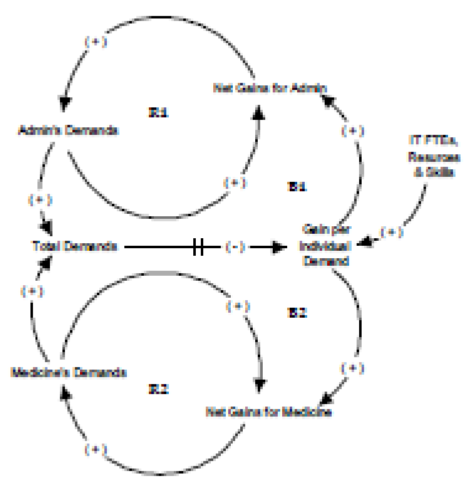
Behavior Over Time

Application - Resource Allocation

In this archetype situation, the complex interaction of individual actions produces an undesirable effect, such as the depletion of a common resource. The archetype can be used to help connect the long-term effects of individual actions to the collective outcome, and develop measures for managing the common resource more effectively.

Example

IT resources are typically organized into a "commons" department, with each part of the organization seeking their support on an as-needed basis. Since separate parts of the organization typically do not keep track of the IT problems in other parts of the organization, it is fairy common for each part of the organization to see the IT department as "its own". When the IT department is crushed under the weight of all the demands placed upon it, its performance for every department begins to erode or fail.



Example: IT Project Requests

Prescriptive Action

- Establish methods for making the cumulative effects of using the common resource more real and immediate to the individual players.
- Re-evaluate the nature of the commons to determine if there are ways to replace or renew (or substitute) the resource before it becomes depleted.
- Create a final arbiter who manages the use of the common resource from a whole-system level.

Seven Action Steps

- Identify the "commons". What is the common resource that is being shared?
- Determine incentives. What are the reinforcing processes that are driving individual use of the resource?
- Determine the time frame for reaping benefits.
- Determine the time frame for experiencing cumulative effects of the collective action.
- Make the long-term effects more present. How can the long-term loss or degradation of the commons be more real and present to the individual users?
- Reevaluate the nature of the commons. Are there other resources or alternatives that can be used to remove the constraint upon the commons?
- Limit access to resources. Determine a central focal point - a shared vision, measurement system, or final arbiter - that allocates resources based on the needs of the whole system.

What Does This Really Mean?

In many respects the Tragedy of the Commons is a classic example of reductionistic thinking. By remaining unaware of the effect of the parts on the whole, people continue to think and behave as though there are no connections within the organization that affect their ability to meet goals and objectives. Focused on their own part, behaving as though it depended on no other, demands on the commons are issued with only the present in mind.

Sustainability is increasingly put forward as a guiding principle for the planet we inhabit. Sustainability has applications within organizations, with respect to their structure and practices, with an eye on the long-term future. Structures that create commons and policies and practices that govern them (leading to depletion or replenishment) are critical success factors.

Ultimately, firms may conclude that structures that include a commons are ineffective means of distributing and allocating resources. Alternately, they may gain insight into how commons have to be governed, and recognize that structures and policies, other than the commons itself, all interact and have a pronounced effect upon the utility the commons bring to organizations.

Appendix C - Case Study Metrics

Case Study Metrics - Page 1

Metric Number	Case Study Element	Data To Calculate	Equation	Variable Name	Comments	Sufficient Data Available?
1	Individual Motivation and Diffusion	Current Investment Rate of Return Chart for Community PV Investment	Net Present Value of Electricity Cost - Net Present Value of the System and Any Operating Costs	A	At what point are investors motivated, and how do the communities compare regarding financial motivation (Investment Rate of Return) on PV investment?	Yes
2	Individual Motivation and Diffusion	Current Level of Residential PV adoption	Straight Value - May triangulate from various sources	B	This establishes how active the market is for the community - Some of this data can help resolve diffusion of innovation positioning.	Yes
3	Individual Motivation and Diffusion	Current Rate of Residential PV Adoption	Straight Value - May triangulate from various sources	C	PV market statistic to demonstrate trends - Will reflect impact of programs and community interest - As above, helps establish diffusion of innovation effects.	Yes
4	Cooperative System Impacts	Current Residential PV Market Electricity Opportunity (Watts) - Note this value is already derated, and is considered the market size	Peak Generation and Purchase at Utility for Electricity Demand Spikes between 11am and 5pm	D	Establishes benefit available to collective, cooperative strategy to eliminate higher cost, peak power (typically natural gas fired turbines or 'peakers' or expensive spot market buy) by decreasing demand through distributed generation with PV at the load; This metric may vary due to reporting differences between the utilities for each city.	Yes
5	Cooperative System Impacts	Total Potential PV Market Size; Market Required to Cover Eletricity Opportunity (Watts)	Electricity Opportunity / 77% Derate Factor	E	Market taking into account the derate factor as described in the PVWatts software offered by NREL.	Yes
6	Cooperative System Impacts	Total Annual Residential PV kWh Generation for Community - Year 1	Potential PV Market Size * Annual PV Generation per Watt	F	This is the actual amount of electricity produced for a PV strategy installation strategy outlined above according to PVWatt output for each location.	Yes
7	Utility Affects	Utility Revenue Drop ($) - Year 1	F * Average Annual Residential kWh Delivery Price	G	This is the drop in utility revenue from residential PV peak period generation defined above.	Yes
8	Utility Affects	Current Average Net Peak Power Price Difference to Utility	Average Peak Power Utility Cost per kWh - Average Annual Residential kWh Delivery Price	H	Often, peak power generation is more expensive than the rate charged to the consumer, which reduces utility margin. Peak reduction through residential PV installation will decrease revenue but does offer potential to actually increase utility margin with residential PV investment.	Yes
9	Utility Affects	Utility Peak Power Margin Loss / Gain ($) with full Residential PV Installation - Year 1	H * F	I	Utility gain or loss in profitability if expensive peak generation is replaced with distributed, residential PV.	Yes

Data Availability Legend:

(dark green)	Data source available and complete
(yellow)	Data source available but not complete (some generality will be applied)
(yellow)	No clear data source available, but general information found

Appendix C - Case Study Metrics (continued)

Case Study Metrics - Page 2

Metric Number	Case Study Element	Data To Calculate	Equation	Variable Name	Comments	Sufficient Data Available?
10	Utility Affects	Infrastructure Investment Reduction Under Distributed PV Model	Straight Value - Company Reported	J	This can be discussed by looking at annual reports and 10k's for the utilities - Actual reductions can be hypothesized, but likely will not be concrete - At a minimum, some clarity can be given regarding the T&D expense change with DG.	Yes
11	Auxillary Community Impacts	Air Quality Impact of Residential PV Installation	Total Annual Utility Emission by Pollutant / Total kWh generated * F	K	This metric assumes PV installations have no emissions from installation and use. EPA air quality data will be reproduced as a baseline, and the reduction of emissions related to electricity production will be estimated based on community electricity generation profile and net offset provided by the residential PV strategy.	Yes
12	Auxillary Community Impacts	Water Consumption Impact of Residential PV Installation	Is highly dependent on generation technology and relationship to use for peak to baseload reduction - Requires more information		As with the Air Quality metric, an estimate of water use for community electricity generation will be developed for the technology types used, and the estimated reduction will be calculated assuming no water is used by the PV. Helps understand the auxillary impacts of conservation when moving to PV.	No
13	Auxillary Community Impacts	Capital Preserved in the Community ($) - Year 1	Total Balance of System Cost for PV Installations + G		This equation assumes utility is privately owned and is headquartered outside the community. Balance of System costs are a percentage of total system cost, which implies equipment pass through.	No
14	Auxillary Community Impacts	Net Job Creation by Migration to Residential PV Generation Peak Model	Number of Installer Positions Gained - Utility reduction with Peak generation offset		This may be difficult to quantify without being in the companies. Deserves general discussion in text.	No
15	Auxillary Community Impacts	Consider educational gain, but this is too complex. It is relevant to the scope of this study but must be addressed in the text.			Many suggest that the number and caliber of electricians in a community grows when distributed generation is embraced. Generally, the community becomes more educated through trade schools and environmental program development in secondary education (and middle / elementary). I've tried to locate statistics to develop this point, but clear city specific information will be challenging.	No

Data Availability Legend:

	Data source available and complete
	Data source available but not complete (some generality will be applied)
	No clear data source available, but general information found

Appendix D - Arizona Goes Solar Output - Residential Grid-Tied Photovoltaic Installations

	Year Installed													
Maricopa County, AZ - Standard ZIP Codes	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Pending	Grand Total
85003						1	2	4	3	2	4	3	2	21
85004		1	1		1				3	2	2	1		11
85006					3	1		2	4	7	10	6	5	38
85007					3	1	3	1	6	10	9	1	4	38
85008								1	1	3	1	1	2	9
85009					1			3	2	4	5		2	17
85012						1	2	3	7	3	2	1	2	21
85013				1	2	3		2	7	5	8	3	2	33
85014			1		3	1	1	5	20	6	14	10	10	71
85015							1	3	4	3	5		4	20
85016								2	7	4	2	3	3	21
85017											1			1
85018					2	1	1	1	2	2				9
85020		1	2		7	3	5	19	33	16	32	11	10	139
85021					2	3	3	7	6	11	9	3	2	46
85022				1	1	3	8	24	41	39	72	20	22	231
85023					1	6		19	21	14	26	7	15	109
85024							2	14	20	28	43	20	9	136
85027				3	2			15	21	19	37	16	13	126
85028		2	1	1	9	4	6	22	41	39	52	22	12	211
85029				1	1	2	1	9	14	20	30	17	10	105
85032	1	1				3	4	23	39	31	54	34	15	205
85034										1				1
85039													1	1
85040			1											1
85044							1							1
85050						1	3	7	25	24	32	18	12	122
85051								2	1	2	5	3	4	17
85053					2		2	11	20	22	37	14	13	121
85054					1			2	5	2	5	4	2	21
85083					1	4	5	16	35	51	63	28	18	221
85085			1		1	2	1	9	23	35	58	25	18	173
85086	1	1		1	2	6	9	55	64	115	222	75	47	598
85087			1		2	1	5	8	20	14	38	21	15	125
85119								1						1
85202			1											1
85204			1											1
85206													1	1
85207		1										1		2
85225								2	8	7	16	4	5	42
85233						2		2	7	7	10	5	4	37
85234					2	1		4	1	6	5	2		21
85250			1	1	1	1	2	3	7	5	2	4	1	28
85251						2	2	4	6	1	3	1	1	20
85253				2	7	5	9	24	35	26	29	5	12	154
85254				3	3	7	12	27	61	49	63	31	9	265
85255			2	2	2	5	5	39	54	61	65	26	24	285
85256													1	1

Appendix D (continued) - Arizona Goes Solar Output - Residential Grid-Tied Photovoltaic Installations

	Year Installed													
Maricopa County, AZ - Standard ZIP Codes	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Pending	Grand Total
85258		1	1		1	4	3	10	21	15	20	9	9	94
85259					3	2	7	14	34	27	25	11	7	130
85260					2	4	10	25	22	38	49	21	10	181
85262			2	1	3	2	9	22	24	27	22	7	5	124
85266	2		2	1			7	39	31	33	38	12	6	171
85281			1			1	2	4	5	5	6	5	1	30
85284				1										1
85295											1			1
85296							2	3	7	5	10	2	3	32
85301									5	8	7	3		23
85303												2		2
85304							2	2	3	7	12	4	4	34
85305													1	1
85306					5	2	4	11	17	15	29	10	13	106
85307								1	2	1		2	1	7
85308					2	6	7	27	50	83	112	50	30	367
85310						5	5	13	34	21	28	15	14	135
85322											4		1	5
85323							1		3		3	1	3	11
85326	1		1		1	1	4	10	27	86	152	61	39	383
85331			2	1	4	8	5	39	61	88	84	39	23	354
85335				1	1	1		4	15	10	31	29	20	112
85337				1				1		3	4	1		10
85338					2	1	2	32	59	60	155	81	48	440
85340			2		2	7	4	24	40	44	89	37	26	275
85342			1				1	4	3	2	6	1		18
85343										1				1
85345					2	2	1	6	16	17	20	10	8	82
85351			1	2	8	6	7	25	47	56	119	43	33	347
85353				1					1					2
85354	1			1	1	1	3	6	11	3	9	3	2	41
85355					1	2	1	7	14	20	34	21	18	118
85361		1			1	2	1	4	5	8	21	6	10	59
85363								2				5		7
85373					2	2	2	16	32	21	83	45	31	234
85374					3	7	8	43	170	132	300	156	66	885
85375			1	2	3	7	6	49	94	133	368	141	54	858
85378										7	17	9	3	36
85379					4	2	1	15	27	43	133	66	38	329
85381								2	4	3	7	1	3	20
85382					1	2	3	12	32	31	73	43	23	220
85383			1	3	4	1	8	56	105	127	230	141	68	744
85387					1	1	7	42	90	77	135	51	33	437
85388						1	1	6	16	34	106	60	39	263
85390					2	1	6	22	22	19	12	6		90
85392					1		1	2	6	14	23	15	8	70
85395				1	5	4	36	128	147	128	242	105	55	851
85396						1	1	14	50	104	225	116	39	550
Grand Total	6	9	28	32	127	156	263	1137	2026	2252	4115	1892	1127	13170

Appendix E - OpenPV Extract for El Paso, Texas

Count of Date Installed	Year Installed												
Portland Zip codes:	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Grand Total
97034					2	2					2	3	9
97035											1	4	5
97080							1				9	18	28
97086										2	10	12	24
97201				1	1			1			4	1	8
97202				2	1	5	5	7	2	1	8	7	38
97203					1		1	1			6	1	10
97204												1	1
97205					1				1				2
97206							1	4	5		14	5	29
97210								1		1	4	1	7
97211						1	3	3	1	41	9	11	69
97212	1			1	2	2	4	6		42	12	4	74
97213						1	3	3	1	28	13	10	59
97214		1		1	1	1	3	1		3	1	8	20
97215	1				1		1	2	1	1	3	5	15
97216								1	1		5	2	9
97217					1	2	2	3		2	10	9	29
97218					2	1		4	1	4	4	2	18
97219					2	3	2	5	1	2	4	1	20
97220					1					4	5	8	18
97221			1	2	4	1	1	2			3	2	16
97222							1			3	8	6	18
97223						1	2	1			19	2	25
97225				1				1		2	5	3	12
97227									1	2		2	5
97229							2	3		8	24	23	60
97230								1	1	4	3	5	14
97231					1		2				1	1	5
97232										8		3	11
97233											2	1	3
97236											5		5
97239				2	3		2	1			1		9
97266				1					1	5	6		13
Grand Total	2	1	1	11	24	20	36	51	17	163	201	161	688

Vita

Michael P. Cole earned his Bachelor of Science in Mechanical Engineering from Oklahoma State University in 1993, minoring in Mathematics and Spanish. Starting as a Production Engineer and Mexico liaison based in Dallas, Texas, Mr. Cole gained engineering positions with increasing responsibility and product life cycle exposure. Mike created value as a designer, researcher, mentee and mentor across a broad range of assignments. These experiences culminated into a management role in General Motors Mexico, patent applications and award, and a Fellowship for graduate studies. Mike enrolled in the dual Masters of Business Administration / Masters of Manufacturing Engineering program at the University of Michigan in 1998, and graduated in 2000.

In 2001 Michael returned to industry in Finance and gained experience in auditing, mergers and acquisitions, customs, and logistics. By 2009, Mike held the role of Global Customs Manager based in Juarez, Mexico, and was operating projects and teams in North America, Asia, and Europe. He received various performance awards in those roles.

Mike enrolled in the Environmental Science and Engineering program at UTEP in 2010 after formative discussions with Dr. Barry Benedict. Since that time, professor Benedict has been program advisor, dissertation Chair, mentor, and "Coach". Mike's dissertation entitled “Integrated Sustainability Decision-Making Framework” was supervised by Dr. Benedict.

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This dissertation was typed by Michael Paul Cole.